PRESIDENTIAL ADDRESS

Cainozoic History of the Vegetation and Climate of the Lachlan River Region, New South Wales

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SYNOPSIS

The history of the vegetation based on palynology of the late Eocene to early Pleistocene sediments is presented here for the Lachlan River region. Grey carbonaceous clays of the alluvium in the valley and in the Hillston region of the eastern edge of the Murray Basin, are the most fruitful for palynology. Pollen has not been preserved upstream of Cowra but silicified wood is found in association with basalts. Early Miocene lava flows dammed the river and the lake which was formed drowned the local vegetation (Bishop 1985a).

The palynological record and interpretations of the vegetation is one of periods of relative stability with small changes and a series of considerable, step-like change. The climate of the time is deduced from the parameters controlling generally similar modern vegetation. The main features are as follows:

1. From late Eocene to late Oligocene — early Miocene, *Nothofagus* is the most abundant pollen group and most of it is the *brassii* type. The vegetation was rainforest with reasonable diversity. The climate was very humid with a precipitation of about or above 1800mm. (The levels of precipitation given here are very general with no great accuracy: the trend is more important.)
2. In the late Oligocene — early Miocene, the *Nothofagus* content declines, particularly the *brassii* type. The vegetation was still rainforest. There was a decrease in precipitation, probably to about 1500mm.
3. In the early — mid Miocene, the Myrtaceae group was relatively more abundant. The assemblages are diverse, however, and contain many low frequency pollen types, which collectively may have accounted for a major portion of the vegetation, which was rainforest.
4. The mid Miocene was a time of considerable change. The *brassii* type of *Nothofagus* disappeared and pollen preservation ceases in the Hillston region.
5. In the ?mid — late Miocene, Myrtaceae were dominant but rainforest taxa were still present. The charcoal record, which had been low in the older, rainforest assemblages, increased considerably, suggesting that the myrtaceous vegetation was mainly wet sclerophyll. The precipitation decreased to about 1000-1500mm, with a definite dry season. Burning had become a part of the environment.
6. In the early Pliocene, *Nothofagus*, the *menziesii* and *fusca* pollen types only, reappeared in the Lachlan Valley and gymnosperms were more abundant. Rainforest had returned, the precipitation increased to more than 1500mm and burning was infrequent.
7. In the mid — late Pliocene, Myrtaceae returned to dominance, precipitation decreased to the former levels of about 1000-1500mm and burning became more frequent.
8. In the late Pliocene — Pleistocene, the rainforest element disappeared and the precipitation decreased to about 500-800mm.
9. The forest cover dwindled and in the Pleistocene Gramineae and Compositae were abundant; indicative of woodland and grassland/herbfields.

These major changes in vegetation and the inferred climatic changes may be related to changes in sea level and coincide with the major developments of circum-Antarctic oceanic circulation and ice cap formation on Antarctica.

INTRODUCTION

The Lachlan River has its headwaters in the gently undulating, swampy Breadalbane Plains at the continental drainage divide of the Central Tablelands. It flows through a

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broad upland valley around Gunning and Dalton. Downstream, the terrain increases in ruggedness and, at Narrawa, the river flows through a steep-sided granite gorge. Alluvial flats of significance commence about 13km upstream of Cowra. Valley width increases with distance downstream and the alluvial flats become extensive. After the river passes through the gap between the Jemalong and Corridgery Ranges it enters extensive plains. About the junction with Willandra Billabong, it flows onto the Western Plains, the surface of the Murray Basin, and eventually joins the Murrumbidgee River (see Fig. 1). For a delightful pictorial account of the Lachlan River and the lifestyles of the people living in the region, see Cowan and Beard (1982).

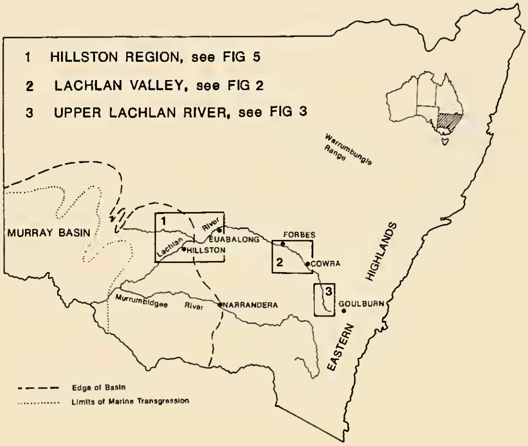


Fig. 1. Locality map. See enlargements for further detail.

In 1957, the Department of Water Resources (formerly the Water Resources Commission of New South Wales, and in 1957, the Water Conservation and Irrigation Commission) began a programme of the investigation into the ground water resources of alluvium of the Lachlan River valley, between Cowra and Forbes. Prior to this date, most bores and wells were sunk for stock water and domestic purposes and did not exceed 30m in depth. There were only a few low-yielding irrigation bores. Test drilling in the valley soon revealed good quality water at greater depths with much higher yields, suitable for irrigation and town water supplies (Williamson, 1986). At the time of writing, there are 174 high-yield bores between Cowra and Jemalong Weir, and of these 166 are used for irrigation and 8 for town water supplies. Investigation has continued downstream of Jemalong Weir and beyond Hillston.

This study of the history of the Lachlan River is based mainly on palynology, geomorphology, and geology. Water Resources has provided samples from its bores for palynology and considerable background information as well. A study of the basalts in headwaters of the Lachlan River (Bishop, 1985a) provides a history of the upper reaches of the river, beyond the extent of the alluvial flats. In all, three areas have been studied in detail and these are shown on Fig. 1.

GEOLOGY AND GEOMORPHOLOGY

The Hillston Region

The Tertiary sediments are some 100m to 170m thick near the edge of the Murray Basin. Thickness increases downstream, i.e. with distance from the edge of the basin to a maximum of about 270m in bore 36342 which is situated over the Ivanhoe Trough. When compared with the Murrumbidgee area to the south, the basement of most of the Lachlan region is shallower and the sedimentary sequence not as thick (Martin, 1984c).

The stratigraphic units used in the non-marine section of the Murray Basin have been adopted from those used in the Victorian part of the basin, with slight modification (Woolley and Williams, 1978; Woolley, 1978). Those relevant to the Lachlan area have been reviewed in Martin, (1984b; 1986a) and are briefly presented below.

The basal Warina Sand of mid—late Eocene age consists of coarse-grained quartz sands and minor dark grey clay lenses and carbonaceous clays. It is only found in the deeper parts of the basin.

The overlying Olney Formation is dominated by grey carbonacous clays and extensive sands. Elsewhere in the basin, thick lignite layers are a feature of the Olney Formation but they are not extensive in the Lachlan area. The basal part is late Eocene and extends into the Miocene.

The Calivil Sand, overlying the Olney Formation, consists of coarse sands and fine gravels with minor bands of carbonacous clay. It is thought to be late Miocene in age. The uppermost Shepparton Formation consists of polymict sands and variegated clays with yellow and brown colours dominant.

Most of the samples used for palynology come from the Olney Formation. The uppermost 60m to 80m do not yield pollen. Upstream from Euabalong to Jemalong Gap, there are few bores. Knowledge of the age of the sediments is reliant on palynology which is presented later.

Lachlan River Valley

Near Cowra, the alluvium is 3-5km wide and erosion terraces are a prominent feature. They become less pronounced further downstream and are not mappable beyond the junction of Mandagery Creek. Drilling has revealed that the alluvium reaches a maximum depth of 61m, some 6km downstream of Cowra. However, 3km upstream of Cowra, the alluvium is only 17m deep. Back Creek, which joins the Lachlan River some 12km downstream of Cowra, has alluvium extending some 48km upstream. The alluvium increases in depth with distance downstream and the maximum depth in Section 7, south of Forbes, is 133m. (See Fig. 2 for localities).

Drilling of the valley downstream of Cowra has revealed a buried 'valley-in-valley' structure. Remnants of an old valley floor are shown as a shelf which maintains a depth of 27-30m below the present drainage level, and it is present in both Back Creek and the Lachlan River valleys. However, the depth of the valley carved into the floor of the old valley, increases markedly with distance downstream (Williamson, 1964). The valley-in-valley structure is thought by Williamson (1986) to be the result of successive tectonic movements, but this is discussed further, below.

Tectonic movements near Cowra have caused a marked change in the upstream section of the Lachlan River but they have not affected Back Creek. Evidence from seismic refraction and bore data indicate that the margin of the area affected is 3km downstream of Cowra with a north-south trend. This margin is thought to be the western edge of the uplifted Eastern Highlands (Williamson, 1986). The valley-in-valley structure is shown with the palynology in Fig. 16B.

The alluvium of the Lachlan Valley consists of two quite distinct formations, the basal Lachlan Formation and overlying Cowra Formation. The characteristics of these formations have been described by Williamson (1986) and are summarized here.

The Lachlan Formation consists of a series of interbedded and interlensed sediments ranging from gravels to clays. The sands and gravels consist almost entirely of quartz of different kinds and sometimes pebbles of chert. The most significant feature of the sands

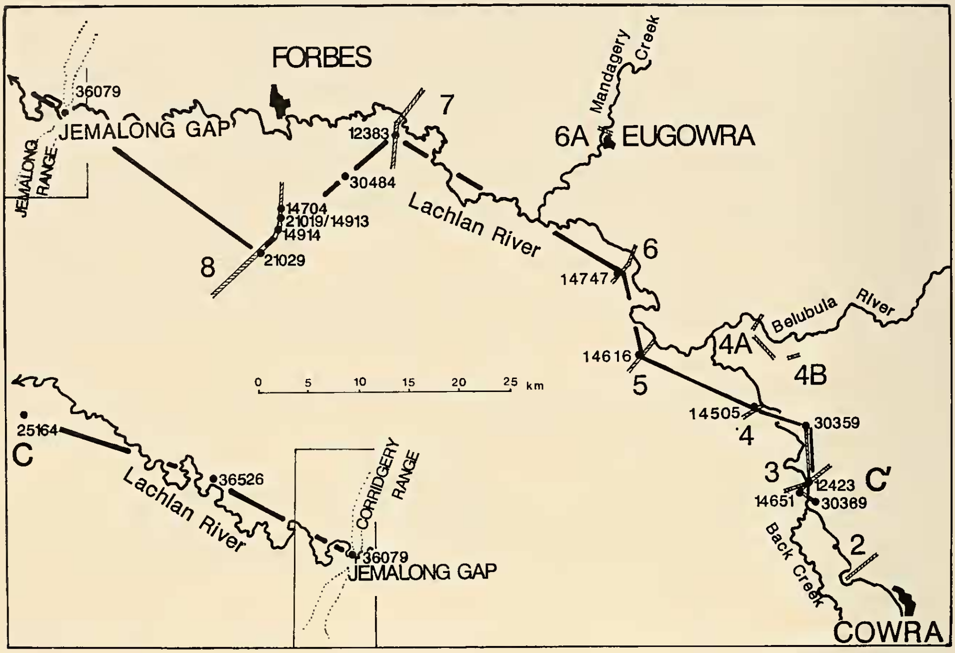


Fig. 2. Lachlan River valley locality map.

and gravels is that they do not contain the resistant rock types found in the catchment today. The fact that the sands and gravels of the Lachlan Formation consist of almost entirely quartz is important for ground water. Quartz is stable and water will become less mineralized in its passage through aquifers of the Lachlan Formation than through those of the Cowra Formation (Williamson, 1964).

The clays of the Lachlan Formation may be divided into variegated clays and carbonaceous clays. The former are usually thinly bedded and streaky. The most common colours are pale brown, yellow, grey and off-white but pink and even red are also fairly common. The carbonaceous clays are the best material for palynology. They are grey to black in colour and occur in lenses irregularly distributed through the Lachlan Formation. These lenses are usually limited in extent and often less than 1m thick though sometimes they may be correlated at the same horizon between two or three bores. These lenses may be 6m in thickness, and range up to 12m.

Wood is occasionally encountered in the sands and gravels. *Podocarpus* sp. has been identified, but most samples are too carbonized for identification (Williamson, 1986).

The Cowra Formation disconformably overlies the Lachlan Formation. The strata range from gravels to clays, all of which are predominantly brown, sometimes pale brown, red-brown, or yellow brown and rarely grey. The sands and gravels contain representatives of the various resistant rock types present in the catchment area today. In this respect, they differ significantly from the Lachlan Formation. The associated silts and clays in the Cowra Formation are predominantly brown and occasionally pale grey in thin layers. There may be greyish mottling near the surface, probably due to leaching. Carbonaceous clays are extremely rare.

Wood was encountered only once in the Cowra Formation in gravels in Bore 12437, Section 4, at a depth of 26m. It has been identified as probably *Eucalyptus resinifera* (R. K.

Bamber, *pers. comm.*), but was beyond the range of carbon dating i.e. older than 34,000 years (Williamson, 1986).

There is another formation, the Glen Logan Gravels, consisting of medium to coarse quartz gravel, usually in a red-brown silty matrix. They occur in elevated positions and often form hill cappings and are worked for road materials. It is thought that they are remnants of a formerly more extensive formation which is stratigraphically below the Lachlan Formation. Williamson (1986) postulates that the Glen Logan Gravels were probably the major source of the quartz gravels in the Lachlan Formation, but this is discussed further, below.

The test drilling in the valley has revealed facets of river history. See Fig. 2 for localities. Back Creek now joins the Lachlan River 8km downstream of Section 2 but its former junction was at Section 2. At Section 4, the ancient course of the Lachlan River went through the southern part of Section 4A instead of its present course, some 6km to the south. About Section 7, the ancient river turned south-west and passed under Section 8, some 15km south of its present course near Forbes. The ancient river passed through the gap between the Jemalong and Corridgery Ranges, as does the present river, for this is the only feasible gap (Williamson, 1986).

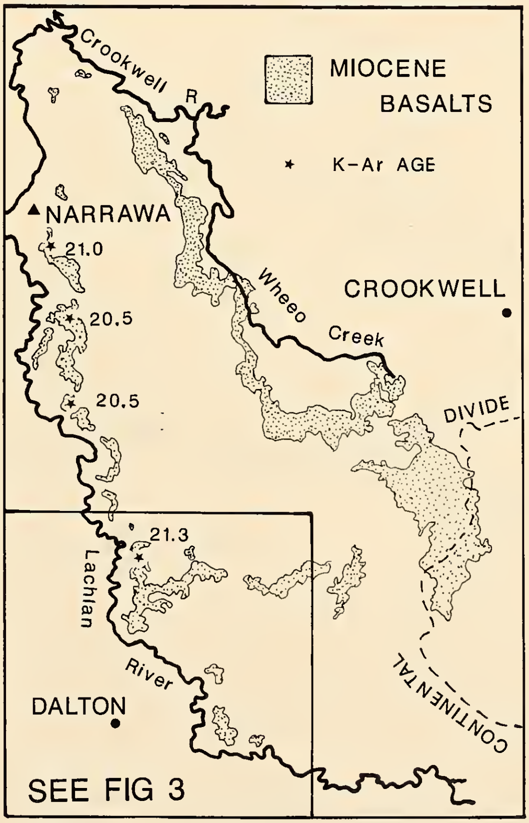


Fig. 3. The Miocene basalts of the Upper Lachlan. Modified from Bishop (1985a).

The upper Lachlan River

Near the headwaters of the Lachlan River, early Miocene channels have been preserved by long narrow tongues of basalt which were extruded into valleys and some tributaries (see Fig. 3). These basalt remnants occur as hilltop residuals as a result of relief inversion by erosion of the surrounding rock. These remnants have flat tops and are of a fairly uniform elevation, as would be expected from lava flows which did not completely fill the valleys (Bishop, Young and McDougall, 1985). The basalt remnants show that the ancient river ran parallel to the present course of the Lachlan and on the eastern side of Narrawa Mountain (Bishop, 1985a; 1987).

The lava flowed westwards down a tributary into the main river, damming the channel. It then flowed northwards for some 15km down the temporary dry river bed. A large lake, thought to be about 16,500 km^2 in area was formed (Fig. 4), presumably drowning the vegetation. Continuing lava flows engulfed the trees and preserved the wood. At least one tree stump has been preserved, apparently *in situ* and fragments of silicified wood are common in the area today (Bishop, 1985a). The stump has been identified as Myrtaceae, with affinities to *Eucalyptus* B. *Acacia* and *Nothofagus* have been identified amongst other wood fragments (Bishop and Bamber, 1985).

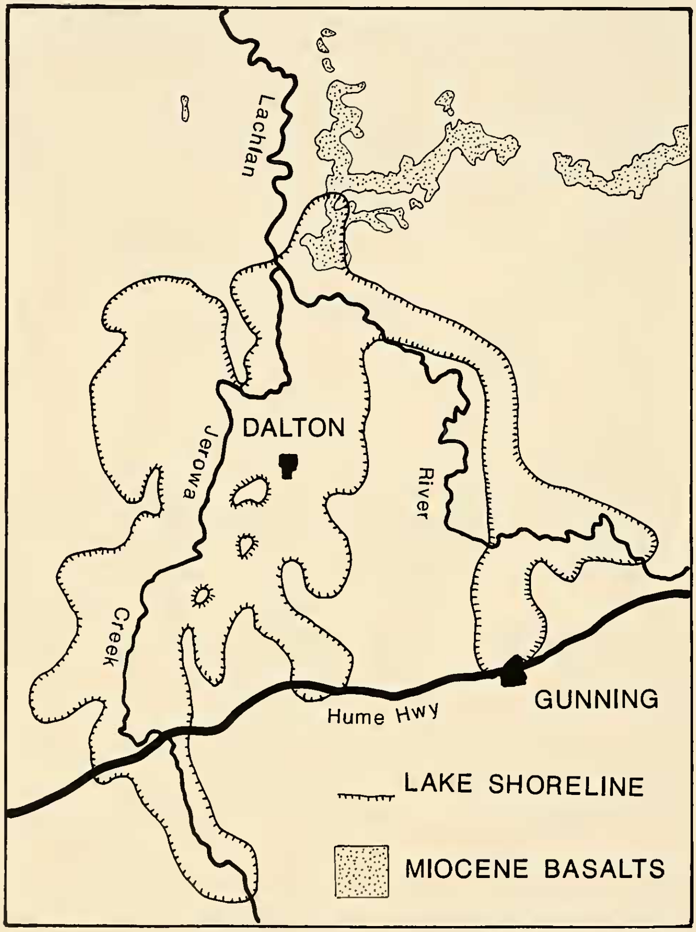


Fig. 4. Probable extent of the Miocene lake formed after the ancient Lachlan River had been damned by lava flows. Modified from Bishop (1985a).

It is not clear how long the lake persisted or what were the events associated with breaching the lava dam. It is thought that the present course of the Lachlan, in the gorge west of Narrawa Mountain, may be attributed to the catastrophic events associated with breaching the dam and draining the lake (Bishop, 1985a).

Pollen has not been preserved in the sediments of these upper reaches of the Lachlan River (Bishop, 1985a).

PALYNOLOGY

Late Eocene to mid Miocene palynofloras

The palynological zones described for the Gippsland Basin (Stover and Partridge, 1973, 1982; Partridge, 1976) are the most appropriate for this study. The zones are identified by the presence of diagnostic species in the assemblages and have been dated from independent evidence of the foraminifera found in the sequence. Extrapolation of the zones in the Gippsland Basin to the Murray Basin required some minor modifications, particularly for subdivision of thick sections of the Oligocene — early Miocene *P. tuberculatus* Zone. These modifications utilize the variation in abundance of selected species and the method is presented in Martin (1984a). Fig.5 presents the palynological zones applicable here.

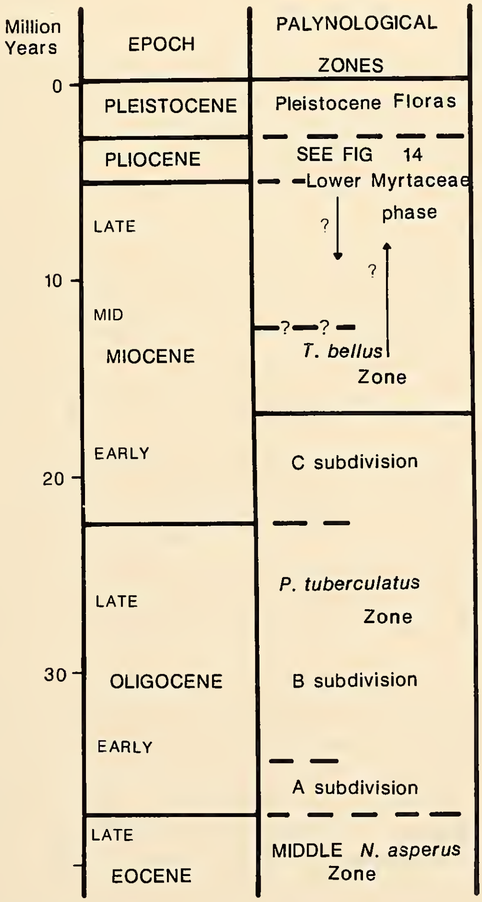


Fig. 5. Palynological zones applicable to the Hillston region. From Stover and Partridge (1973, 1982); Partridge (1976), with the modifications of Martin (1984a).

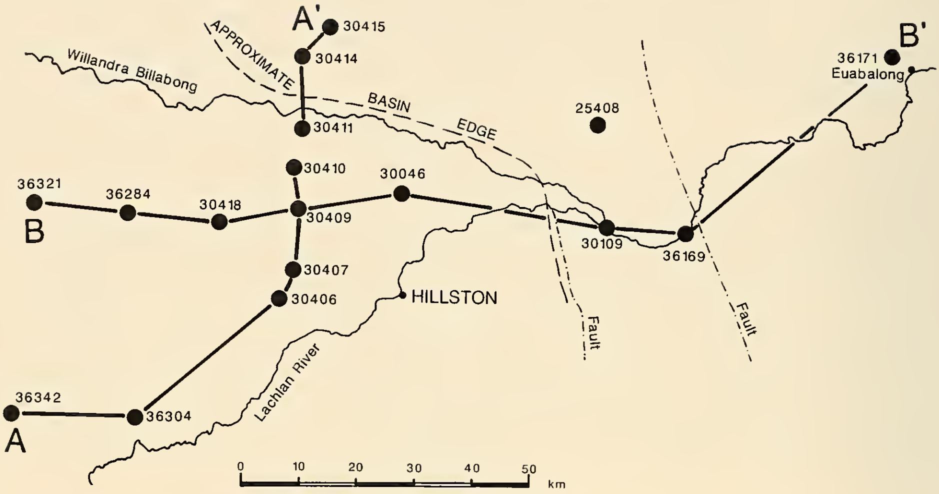


Fig. 6. Hillston region showing location of bores and sections.

Two sections in the Hillston region (see Figs 6-8) show the distribution of the palynological zones. The oldest zone present is the late Eocene Middle *N. asperus* Zone and it is restricted to the Murray Basin. Pollen preservation ceases in the early Miocene and the upper or C subdivision of the *P. tuberculatus* Zone is the youngest in the Murray Basin. Upstream of the Lachlan River, beyond the eastern edge of the basin, the younger mid Miocene *T. bellus* Zone and Pliocene sequence may be present (see Fig. 8).

Fig. 9 presents the counts of the pollen groups in Bore 36342, Tom's Lake, the deepest of this study. For a definition of the groups, see Appendix 1. There is relatively little change between the pollen groups of the Middle *N. asperus* Zone and the A and B subdivisions of the *P. tuberculatus* Zone The C subdivision shows a considerable decrease in *Nothofagus*, particularly the *brassii* type, and a slight increase in Myrtaceae. (The importance of this change is discussed further below.) Besides these abundant pollen groups, there are a number of low percentage angiosperms listed in Appendix 2. There are others which have not been named and for which botanical affinities are unknown, particularly tricolpate and tricolporate pollen types. On the whole, these assemblages are diverse.

The subdivision of the *P. tuberculatus* Zone into three parts (see Fig. 9) is only possible in the deep bores of the Lachlan region. Elsewhere, the A and B subdivisions cannot be identified. The C subdivision, however, is present over the whole area, as shown in Figs 7 and 8 (see also Martin, 1984c). In this respect, the Lachlan area of the Murray Basin differs from the Murrumbidgee area where the three subdivisions are recognized over the whole area (Martin, 1984b).

The Middle *N. asperus* Zone is distinctive with a variety of proteaceous type pollen. There may be up to nine species of *Proteacidites* which may account for 10% of the total pollen count although 5% is more common. A number of these species, mainly the larger pollen types, do not extend into the younger zone above. The diversity and abundance of the proteaceous type pollen decreases in the subsequent, younger assemblages. As well as *Proteacidites* spp. there are a number of distinctive angiosperm pollen types which are not found in younger zones (see Appendix 2).

Nothofagus is the most abundant group in the *P. tuberculatus* Zone. The *brassii* type usually accounts for most of this group but some assemblages have a high proportion of *N. flemingii* of the *fusca* pollen type (see Fig. 9). High *N. flemingii* assemblages may be found

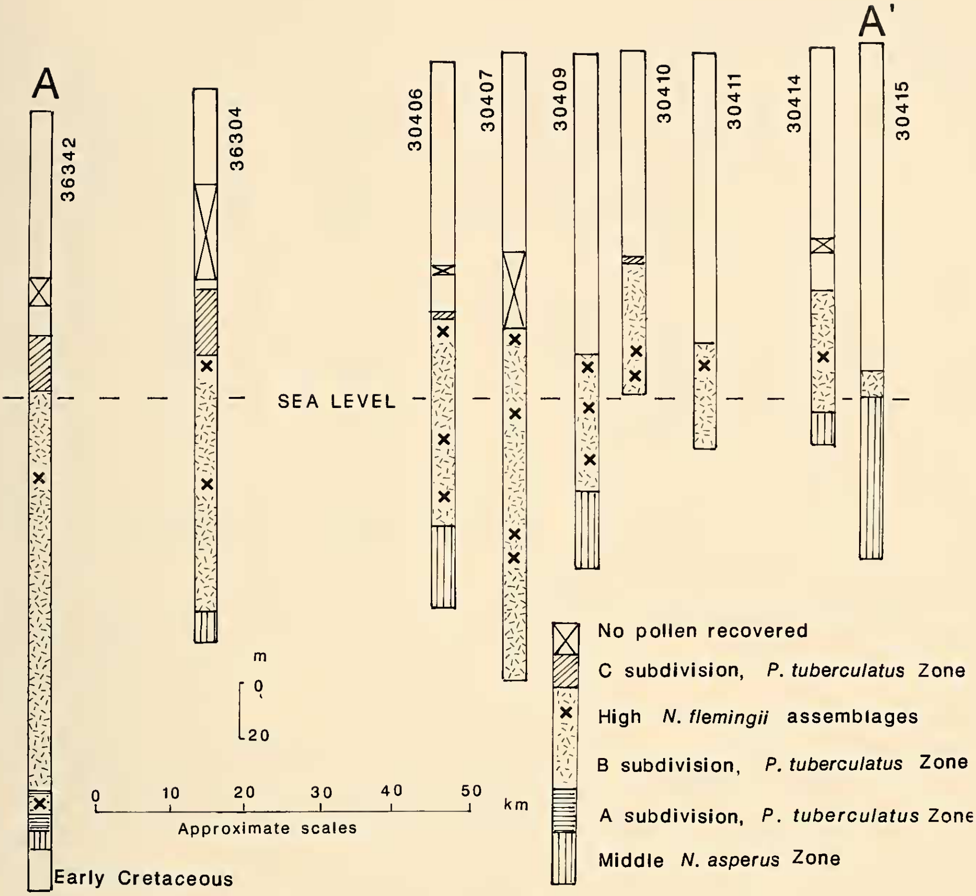


Fig. 7. The palynological zones in Section A-A^1 of the Hillston region.

anywhere in the *P. tuberculatus* Zone of the Lachlan area (see Fig. 7) of the Murray Basin, unlike the Murrumbidgee area to the south where such assemblages are restricted to two, well-defined layers (Martin, 1984b; 1986a; 1986b).

In the C subdivision of the *P. tuberculatus* Zone, the *Nothofagus* content declines, especially the *brassii* type. This decline is moderate in the Lachlan region, as shown in Fig. 9, but in the western part of the basin, the decline is much greater (Truswell *et al.*, 1985). The Myrtaceae group increases slightly here (Fig. 9), but it becomes the major pollen group with the decline in abundance of *Nothofagus* (Martin, 1986a; 1986b). As well, there is an increase in diversity and abundance of the tricolpate — tricolporate pollen types in this subdivision. The proteaceous pollen content may increase somewhat, but the pollen types are relatively small, more like *Helicia — Orites*, hence distinct from the late Eocene proteaceous content.

There are only a few of the *T. bellus* Zone assemblages and they are found upstream from the edge of the Murray Basin. The identification of this zone relies on several diagnostic species, but quantitatively, the assemblages are little different from those of the upper part of the *P. tuberculatus* Zone. Figs 10 and 11 present the counts of some *T. bellus* Zone assemblages and Appendix 2 shows the low percentage angiosperms. The seemingly poor

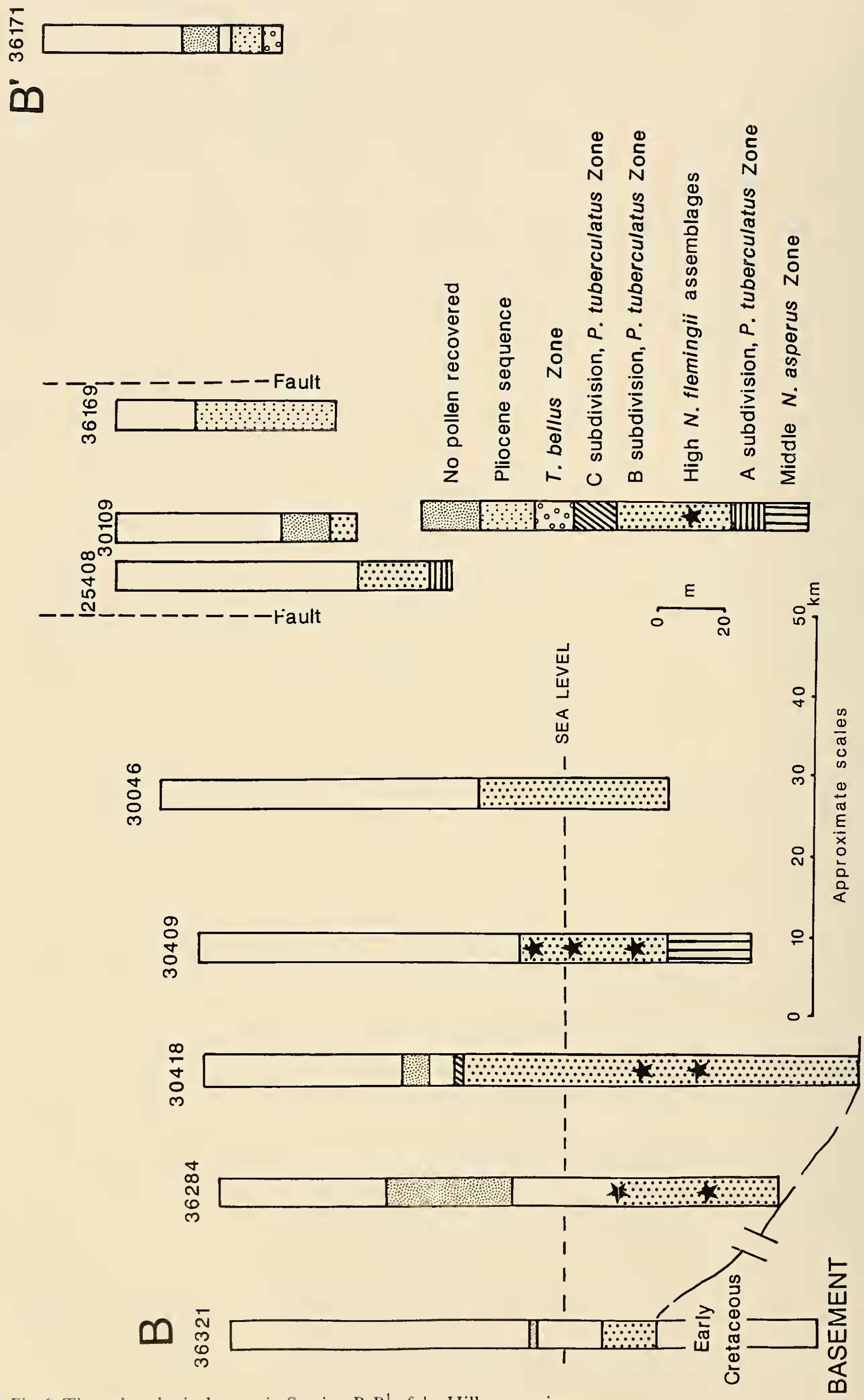


Fig. 8. The palynological zones in Section B-B^1 of the Hillston region.

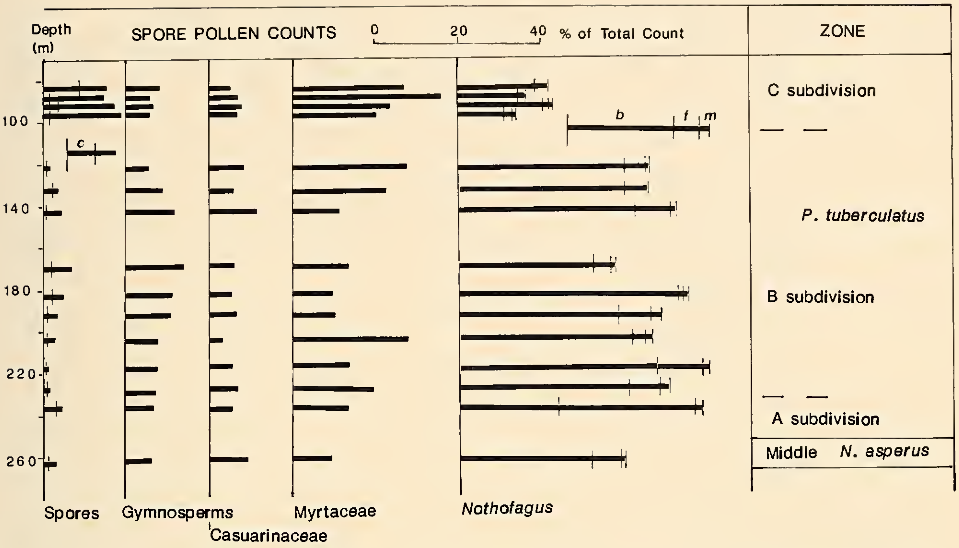


Fig. 9. The abundant pollen groups (see Appendix 1) for bore 36342 of the Hillston region. C. *Cyathea*, the left hand portion of the spore count. b, *brassii* type, f, *fusca* type and m, *menziesii* type from left to right, respectively. Those counts of *Nothofagus* showing only two divisions are the *brassii* and *fusca* types only. Low percentage taxa are not included (see Appendix 2).

representation of pollen types in Appendix 2, in comparison with the older zones is a result of many fewer of *T. bellus* zone assemblages which are, however, just as diverse as the upper part of the *P. tuberculatus* Zone. Unnamed and unknown tricolpate — tricolporate pollen types are a feature here.

The Relationship of the *T. bellus* Zone to the 'Pliocene' Sequence

The *T. bellus* Zone and a good Pliocene sequence are found in a bore at Jemalong Gap (Fig. 10). Both also occur in a bore at Euabalong (Fig. 11) but the Pliocene sequence there is not as extensive as that at Jemalong Gap. Prior to this study, only one other bore, at Narrandera (Martin, 1984b), had been found to contain both, hence a detailed comparison is warranted.

At Jemalong Gap, the *T. bellus* Zone contains two diagnostic species *Triporopollenites bellus* and *Symplocoipollenites austellus* (Stover and Partridge, 1973). The *T. bellus* Zone at Euabalong has only the latter. *S. austellus* occurs in the Myrtaceae phase immediately above the *T. bellus* Zone in both bores (and elsewhere, as discussed further below). The assignment of these assemblages to the Myrtaceae phase is based on an increase in Myrtaceae and minimal *Nothofagus*, especially the *brassii* group. The small amount of this pollen type in the basal two assemblages of the lower Myrtaceae phase at Jemalong Gap, 2% or less (see Fig. 10), could easily result from reworking of older assemblages.

Stephanocolpites oblatus, commonly present in the Pliocene sequence, is found in the *T. bellus* Zone of both bores. It is found occasionally in older zones as well (see Appendix 2). A number of distinctive early Tertiary angiosperms which range into the *T. bellus* Zone, e.g. *Malvacipollis subtilis*, *Triporopollenites endobalteus* and *Polyorificites oblatus*, as well as the nominate species of the zone, *T. bellus*, are usually lacking from the Myrtaceae phase (see Appendices 2 and 3) but, given the variability of the latter (discussed further below), this may not be entirely reliable. Thus the main feature used to differentiate the Myrtaceae

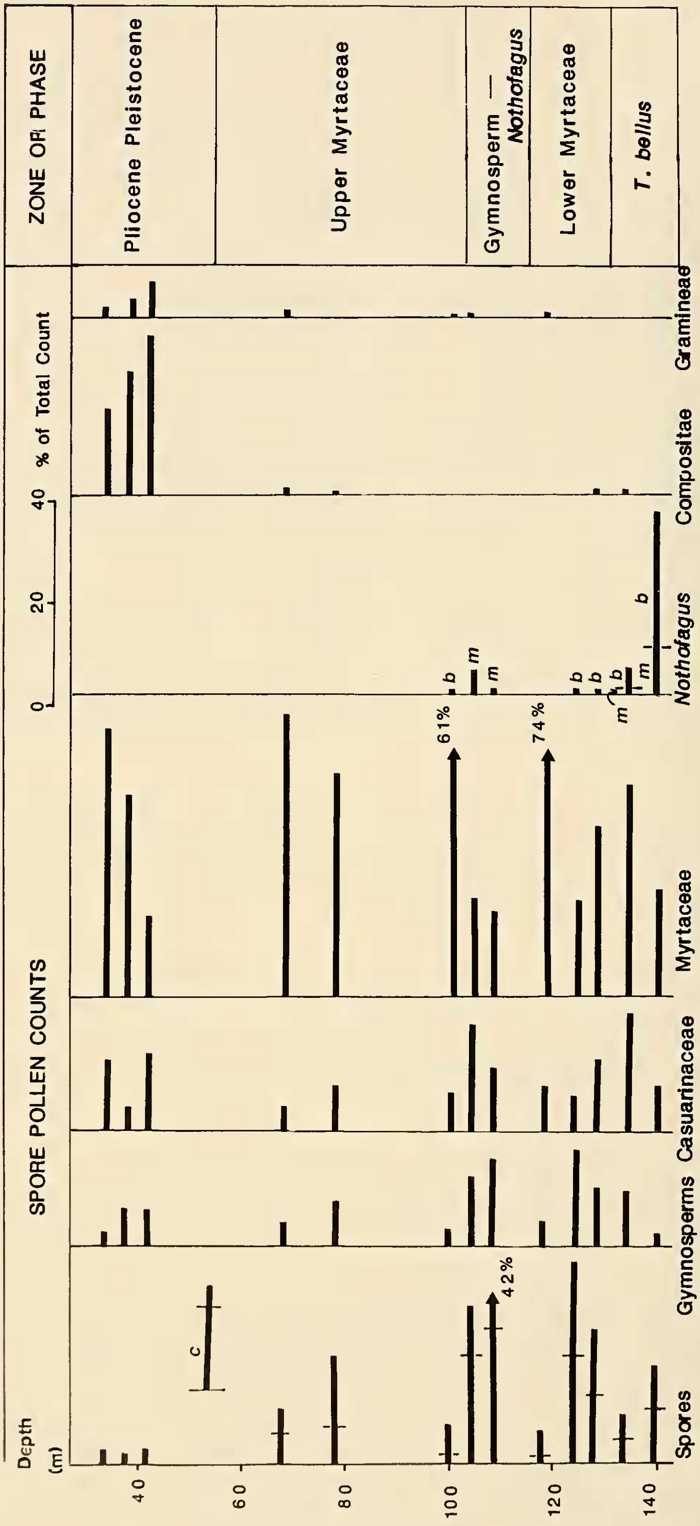


Fig. 10. The abundant pollen groups (see Appendix 1) at Jemalong Gap, bore 36079. C, *Cyathea*. b, *brassii* type. m, *menziesii* type. Low percentage taxa are not included (see Appendices 2 and 3).

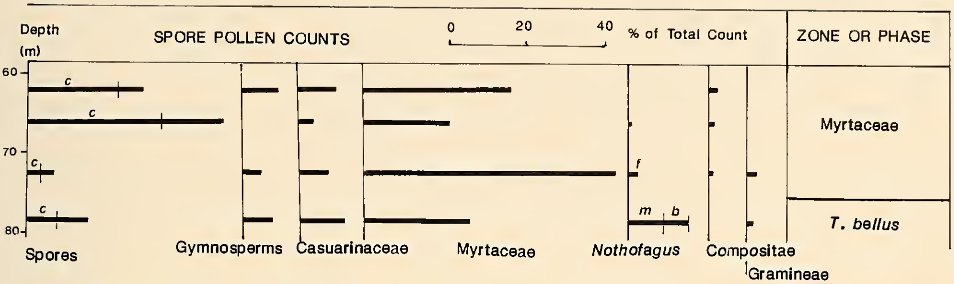


Fig. 11. The abundant pollen groups (see Appendix 1) at Euabalong, bore 36171. C, *Cyathea*. b, *brassii* type. f, *fusca* type. m, *menziesii* type. Low percentage taxa are not included (see Appendices 1 and 2).

phase from the *T. bellus* Zone is the low proportion of *brassii* type *Nothofagus*.

The upper part of the *P. tuberculatus* Zone may have a high content of Myrtaceae (discussed previously). However, near the eastern edge of the Murray Basin, it also has appreciably more than a few percent of the *brassii* type of *Nothofagus* as well as more of the typical early Tertiary angiosperms, hence is unlikely to be confused with the Myrtaceae phase. Near the western edge of the basin, the upper part of the *P. tuberculatus* Zone has more Myrtaceae and very little of the *brassii* type (Truswell *et al.*, 1985; Martin, 1986a) but a Pliocene sequence has not been identified here.

The 'Pliocene' Palynofloras

The Pliocene sequence is described in Martin (1973b) and has been divided into informal 'phases'. This description was based almost entirely on one bore, 14747 of Section 6, in which the average of all the assemblages for the phase was presented. With subsequent work, a total of some forty bores have been examined from the Lachlan River valley, hence the Pliocene sequence is re-described here with an assessment of the variability. Bore 14747, which shows the best sequence in the Lachlan River valley, is presented here again (Fig. 12) to show the variability found in the phases. This present report does not contradict or make substantial alterations to the original descriptions.

Myrtaceae phase

Myrtaceae is the abundant pollen group and usually constitutes 30-40% of the total pollen count, but some assemblages may have as much as 70%. Spore content is moderate, usually 30% or less. The content of gymnosperm pollen is moderate to low, less than 20% and *Podocarpus* is usually the most common in this group. *Nothofagus* is sometimes present but only in small amounts, 5% or less. Compositae and Gramineae are usually present in low quantities, 5% or less. Cyperaceae and Restionaceae are occasionally present, also in low quantities of 5% or less.

Some taxa are only recorded in low percentages that show little variation. These taxa usually present include *Haloragis* and Proteaceae (excluding Banksieae) whereas *Tasmannia* and *Micrantheum* are sometimes present. Infrequent occurrences include Anthocerotae, *Acacia*, *Dodonaea*, Banksieae Epacridaceae (tetrad pollen type), *Symplocos*, *Quintinia* and *Myriophyllum* whereas *Monotoca*, *Coelebogyne*, Gyrostemonaceae, *Sparganium*, *Macaranga-Mallotus* and and Goodeniaceae are rare. Unidentifiable tricolpate/tricolporate angiosperm grains usually account for 10% or less of the total pollen count.

The original description of the Myrtaceae phase included *Casuarina*, i.e. the Myrtaceae — *Casuarina* phase. High percentages of Casuarinaceae are somewhat erratic and are discussed further, below.

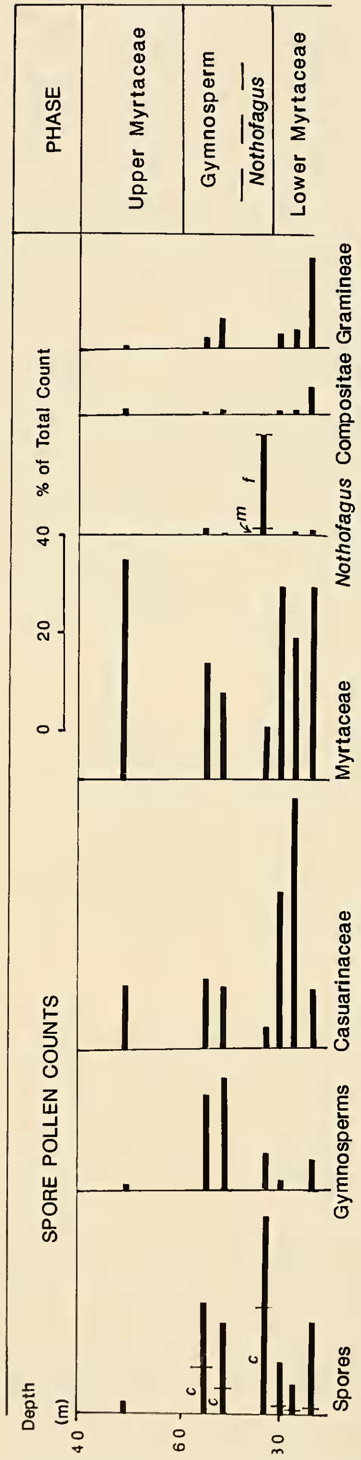


Fig. 12. The abundant pollen groups (see Appendix 1) of bore 14747, Section 6, Lachlan River valley. C, *Cyathea.* f, *fusca* type. m, *menziesii* type. Low percentage taxa are not included (see Appendix 3).

Nothofagus phase

Nothofagus is relatively abundant, over 10% with the highest value of 29%. The *fusca* pollen type, *Nothofagus brachyspinulosa*, is the most common with smaller amounts of the *menziesii* type, *Nothofagus aspera*. The *brassii* pollen type which was abundant in the early and mid Tertiary is present as very minor quantities (1-5%), and in this respect the *Nothofagus* content of these Pliocene assemblages is quite distinct from that of the older, *Nothofagus*-dominated assemblages.

Spore content is moderate (20-30%) with a slightly greater diversity than that of the Myrtaceae phase. The gymnosperm content is usually less than 20% and the composition of the group is much the same as that for the gymnosperm phase (discussed below). However, the single occurrence of *Lagerostrobus franklinii* in the Pliocene is found in the *Nothofagus* phase. The Myrtaceae content is relatively low, less than 20%. The low percentage taxa register in much the same way as that described above for the Myrtaceae phase.

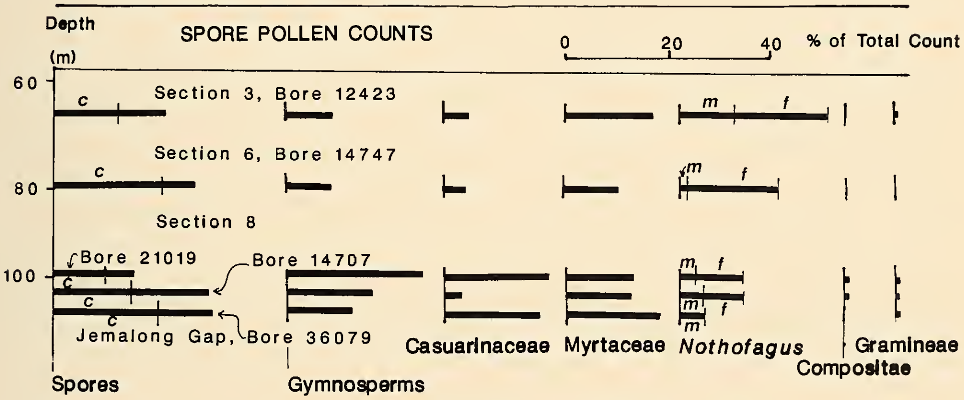


Fig. 13. The *Nothofagus* phase in the Lachlan River valley, bores arranged sequentially downstream. Jemalong Gap does not meet the definition of the *Nothofagus* phase but it is in the stratigraphic position of this phase and included for comparison. C. *Cyathea*. m, *menziesii* type. f, *fusca* type. Low percentage taxa are not included (see Appendix 3).

Fig. 13 shows the pollen spectra of the *Nothofagus* phase, sequentially downstream. The percentage of *Nothofagus* decreases with distance, downstream. Jemalong Gap, with 4.5% does not meet the definition of the *Nothofagus* phase, but there is a peak and it occurs at the expected stratigraphic level of the *Nothofagus* phase (discussed further below). This low percentage could well result from long distance transport, which, however, would coincide with the *Nothofagus* phase further upstream. Jemalong Gap is included in Fig. 13 for comparison.

The Gymnosperm phase

Gymnosperm pollen exceeds 20% of the total count. *Podocarpus* is usually the most abundant of the group, but other taxa may be more abundant, e.g. Cupressaceae, *Dacrycarpus* or *Phyllocladus*. *Dacrydium* and Araucariaceae are usually present but the latter does not exceed 6%. *Microcachrys* is occasionally present in very low frequencies.

Spores, Myrtaceae and Casuarinaceae are all moderate and values rarely exceed 20%. Occurrence of the low percentage taxa are much the same as that for the Myrtaceae phase.

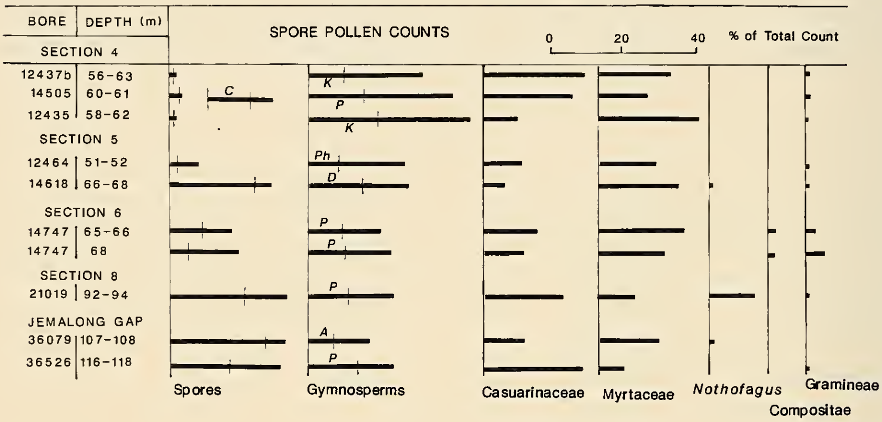


Fig. 14. The gymnosperm phase in the Lachlan River valley, bores arranged sequentially downstream. C, *Cyathea*. The most abundant gymnosperm of the group is shown thus: K, Cupressaceae, P, *Podocarpus*. Ph, *Phyllocladus*. D, *Dacrycarpus*. A, Araucariaceae. Low percentage taxa are not included (see Appendix 3).

Fig. 14 shows the pollen spectra of the Gymnosperm phase, arranged sequentially downstream. The best development is upstream at Section 4, but the decline downstream is not as marked as that for the *Nothofagus* phase. One *Nothofagus*-phase assemblage at Section B also meets the definition of the gymnosperm phase. At Jemalong Gap, the highest percentage of gymnosperms is slightly less than that in the definition, but this assemblage also contains the highest *Nothofagus* value of the Pliocene sequence in this bore , thus these two high values occur in the expected stratigraphic position (discussed further below). The Jemalong Gap high gymnosperm assemblage is included in Fig. 14 for comparison.

High Casuarinaceae Content

A more specific identification of Casuarinaceae pollen is difficult for there is continuous variation through *Gymnostoma* and *Casuarina* (Kershaw, 1970a). Some assemblages have a high content of Casuarinaceae, 50% or more of the total pollen count. These assemblages are otherwise typically those of the Myrtaceae phase. The distribution of the high percentages of Casuarinaceae do not show any clear patterns (discussed further below), hence this feature is not included in the definition of the phases.

High spore content

Some assemblages have an exceptionally high spore content (50-70%). *Cyathea* is usually the most abundant taxon throughout the Pliocene and it may be exceptionally high in these assemblages. There is usually a greater diversity of spores and most of them are ferns. Because of the high spore content, the percentages of other groups are depressed and these assemblages may not fit into any of the phases described above. Some of them, however, have an appreciable Myrtaceae content and could be included in the Myrtaceae phase.

Stratigraphic Relationships of the 'Pliocene' Sequence

As originally described (Martin, 1973b), the lower Myrtaceae phase is the oldest of the sequence and forms a relatively thin part of the sequence over the valley basement. This is overlain by the *Nothofagus* and then the gymnosperm phases, both relatively thin. Above these, the upper Myrtaceae phase forms the uppermost part of the Pliocene sequence. Thus the *Nothofagus* and gymnosperm phases divide the Myrtaceae phase into a lower and upper component, with no means of distinguishing the two from the composition of the assemblages (see Appendix 3). The upper Myrtaceae phase accounts for the largest part of the section and is usually one half to one third of the total Pliocene sequence. Fig. 15 presents the relationship of the phases.

The distribution of the Pliocene phases in the sections across the valley is shown in Fig. 16 and Fig. 17 shows C-C^1 section along the length of the valley (see Fig. 2 for localities.). It can be seen that the whole sequence increases in depth with distance downstream.

The *Nothofagus* phase has been considered as a marker horizon within the Pliocene. The evidence from the Lachlan River valley to support this hypothesis is rather sparse as only five *Nothofagus* phase assemblages have been recovered. There is no evidence to the contrary, either. In a broad sense, the *Nothofagus* phase is still considered a satisfactory marker horizon and the palaeoecological reasons for this are discussed later. However, if levels between bores are extrapolated, then a high degree of precision should not be expected for these are largely fluviatile sediments and cut and fill associated with the changes in the river system may produce a complex stratigraphy. This is probably the reason for the *Nothofagus* phase in Bore 14745 being some 12m below that in Bore 14747, which is only 0.7km distant. See section 6 in Fig. 16E.

The gymnosperm phase occurs above the *Nothofagus* phase in only one bore. All of the other gymnosperm phase assemblages occur in bores which do not have the *Nothofagus* phase or else coincide with the latter. In the upstream part of the valley, both the *Nothofagus* and gymnosperm phases occur close to the floor of the valley (see sections 3 and 4 in Fig. 16). Thus there is doubt whether the gymnosperm phase always occurs stratigraphically above the *Nothofagus* phase. Given the distribution of the two phases, an equally valid hypothesis would be a contemporary mosaic of the two kinds of vegetation (discussed further under palaeovegetation). Thus it may be more prudent to consider the *Nothofagus* and gymnosperm phases as contemporaneous events.

Stratigraphically, the high spore assemblages occur roughly about the same levels or below those of the *Nothofagus* and gymnosperm phases (see Fig. 18). Curiously, most of the high Casuarinaceae assemblages are found about these levels also (discussed under palaeovegetation).

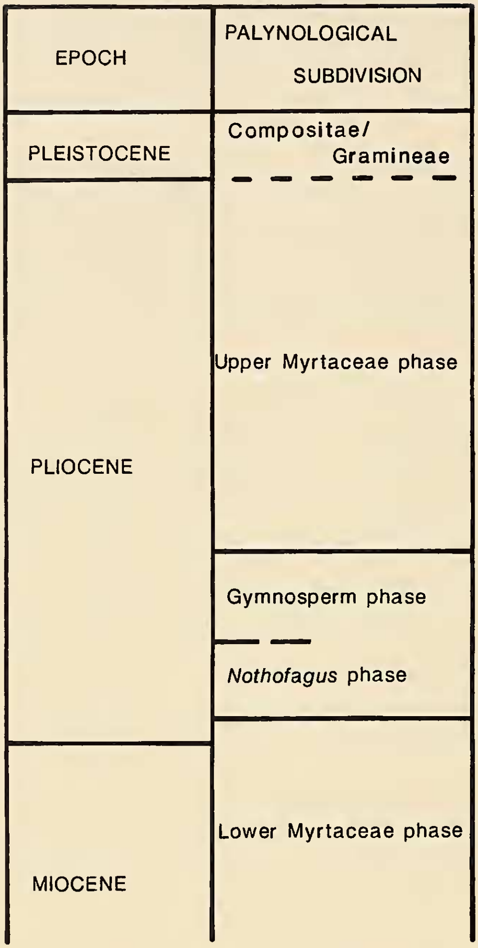


Fig. 15. The relationship of the phases in the ?mid Miocene-Pliocene sequence.

Towards the top of the upper Myrtaceae phase, diversity is reduced and the content of Compositae and Gramineae increases. It may be difficult to distinguish the uppermost Pliocene from Pleistocene assemblages (discussed further below).

Dating the 'Pliocene' Sequence

The lower Myrtaceae phase overlies the *T. bellus* Zone, as discussed previously, but dating the boundary is problematical.

In Section 6A near Eugowra on Mandagery Creek, basalt has been intersected in the bores. There is 9.4m of alluvium below the basalt (Williamson, 1986) but pollen was not recovered from these sediments. The texture, mineralogical and chemical composition of the basalt in the bores is sufficiently similar to the basalt outcrop at Toogong, some 21km upstream, to allow a common source of both the basalts (Williamson, 1986). The Toogong basalt has been dated at 12.2 million years (Wellman and McDougall, 1974).

The assemblages above the basalt contain 4-6% of *Nothofagus*, insufficient to qualify for the *Nothofagus* phase. One assemblage fits the Myrtaceae phase and the other has a high spore content. There is a good representation of rainforest taxa which is usually a feature of the older parts of the Pliocene sequence. However, the location of these bores, in the narrow, steep-sided valley of Mandagery Creek would favour rainforest taxa (discussed further below), hence its position in the sequence is uncertain. Hence the basalt date indicates that some of the Myrtaceae phase is younger than 12.2 million years.

Basalts dated at 17 million to 14 million years (Wellman and McDougall, 1974) overlie lake sediments at Chalk Mountain in the Warrumbungle Range. Two pollen assemblages from these sediments have been described (Holmes *et al.*, 1983). Both are generally similar to the oldest of the Myrtaceae phase encountered in the Lachlan River System. One assemblage has 0.5% of the *brassii* type of *Nothofagus* and there is a variety of rainforest angiosperms. However, gymnosperms are unusually abundant for the oldest part of the Myrtaceae phase. It is thought that a montane lake habitat may not be strictly comparable with the alluvial flats of a broad river valley and this may account for the difference. However, given that there is some uncertainty about the boundary between the *T. bellus* Zone and the Myrtaceae phase, an alternative interpretation is that these Chalk Mountain assemblages are youngest *T. bellus* Zone. If this alternative interpretation is accepted, then they are rather different from the *T. bellus* Zone assemblages of the Lachlan River System. Thus evidence from the Chalk Mountain assemblages suggests that the base of the lower Myrtaceae phase, i.e. the 'Pliocene' sequence, may be as old as 17 million to 14 million years, or middle Miocene.

There is no evidence to date the *Nothofagus*/gymnosperm phase. However, inference from interpretations of the palaeovegetation and changing sea levels (both topics discussed further below) suggest that it coincided with the early Pliocene highstand sea level.

'Pleistocene' Palynofloras

Only a few Pleistocene assemblages have been recovered from the Lachlan River system. They are presented here (see Fig. 18) for comparison with the Pliocene sequence.

Myrtaceae is still relatively common with some high values, about 40%. Other assemblages may have fairly low values, less than 20%. Casuarinaceae is usually quite low, less than 5% although there are a few assemblages with moderately high values of about 30%.

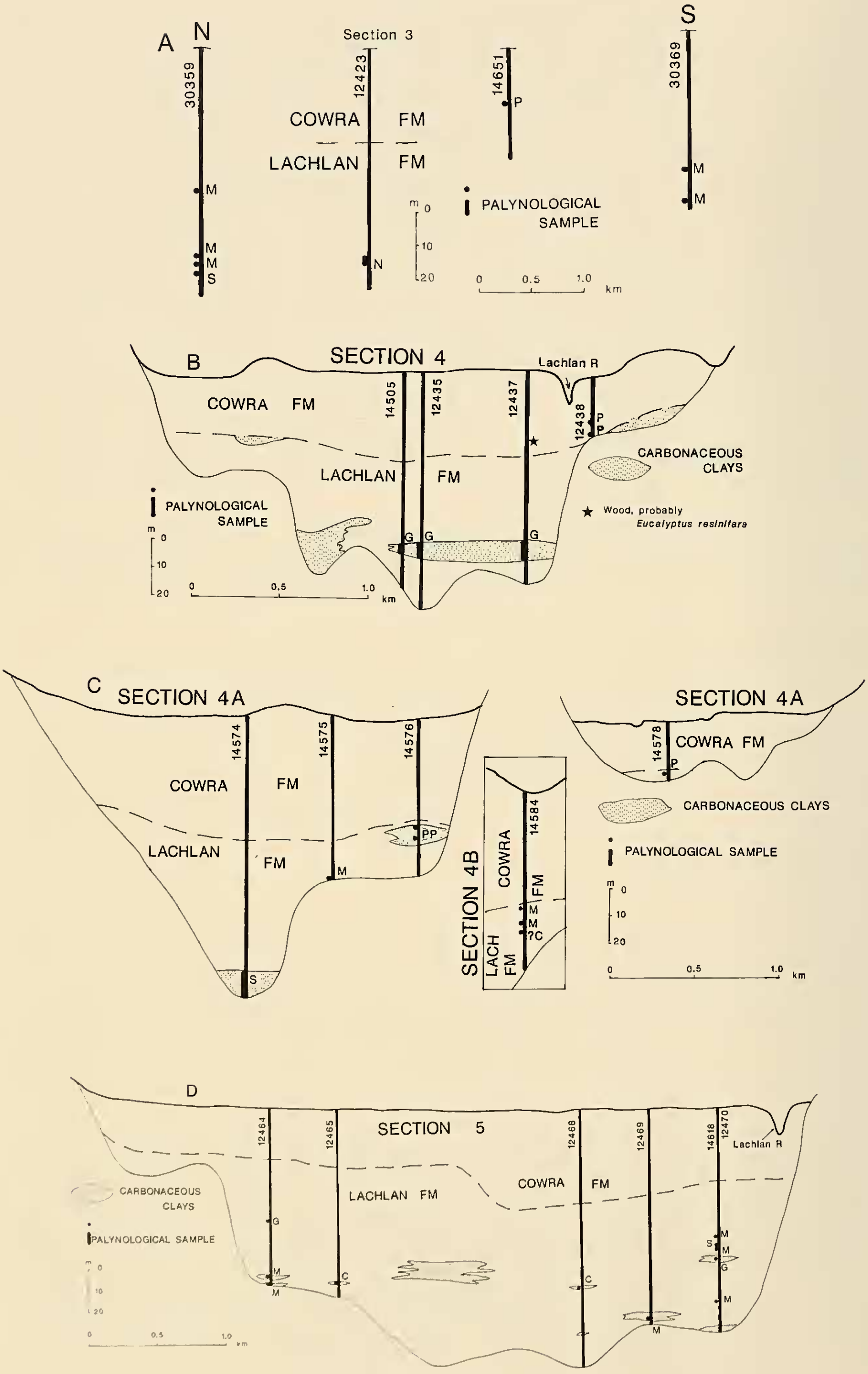
Spore content is low, usually less than 8% and of restricted diversity. Anthocerotae is usually present and the most abundant spore. *Cyathea* is absent from all except one of the assemblages and other ferns are minimal.

Gymnosperm content is low, usually less than 5%. Cupressaceae, Araucariaceae and *Podocarpus* are the only taxa found here.

Compositae is always present, usually with more than 20%. There are some very high values, the highest being 64%. Two pollen forms are almost entirely restricted to the Pleistocene, Cichorieae and *Tubulifloridites pleistocenicus*. Gramineae is usually present in values greater than 10%, sometimes up to 30%. Chenopod/amaranth is also usually present but in low quantities, less than 7%. *Polyporina granulata* is restricted to the Pleistocene. Cyperaceae and *Haloragis* are usually present whereas Restionaceae and *Sparganium* are rare.

The shrubby element, viz. *Acacia*, Banksiae, other Proteaceae, Epacridaceae, *Monotoca* and *Micrantheum* are occasionally present. Unidentifiable tricolpate/tricolporates values are usually very low. The rainforest element is absent or rare. The high pollen producers, viz. *Cyathea*, *Nothofagus* and most gymnosperms are absent or present in such low percentages that they may represent long distance transport or reworking. Other rainforest taxa such as Cupaneae, *Tasmannia*, *Quintinia* and *Symplocos* are entirely absent.

The deepest of these assemblages are intermediate between those of the Pliocene and the Pleistocene. They have a good representation of Myrtaceae and Casuarinaceae, virtually no rainforest element and relatively low Compositae.


A
N
Section 3
S
30359
12423
14651
30369
COWRA FM
LACHLAN FM
M
M
M
S
N
P
M
M
m 0
10
20
PALYNOLOGICAL SAMPLE
0 0.5 1.0 km
B
SECTION 4
Lachlan R
COWRA FM
14505
12435
12437
12438
P
P
CARBONACEOUS CLAYS
LACHLAN FM
PALYNOLOGICAL SAMPLE
Wood, probably Eucalyptus resinifera
m 0
10
20
G
G
G
0 0.5 1.0 km
C
SECTION 4A
14574
14575
14576
COWRA FM
LACHLAN FM
PP
M
S
SECTION 4B
14584
COWRA FM
LACH FM
M
M
?C
SECTION 4A
14578
COWRA FM
P
CARBONACEOUS CLAYS
PALYNOLOGICAL SAMPLE
m 0
10
20
0 0.5 1.0 km
D
12464
12465
SECTION 5
12468
12469
14618
12470
Lachlan R
CARBONACEOUS CLAYS
LACHLAN FM
COWRA FM
PALYNOLOGICAL SAMPLE
G
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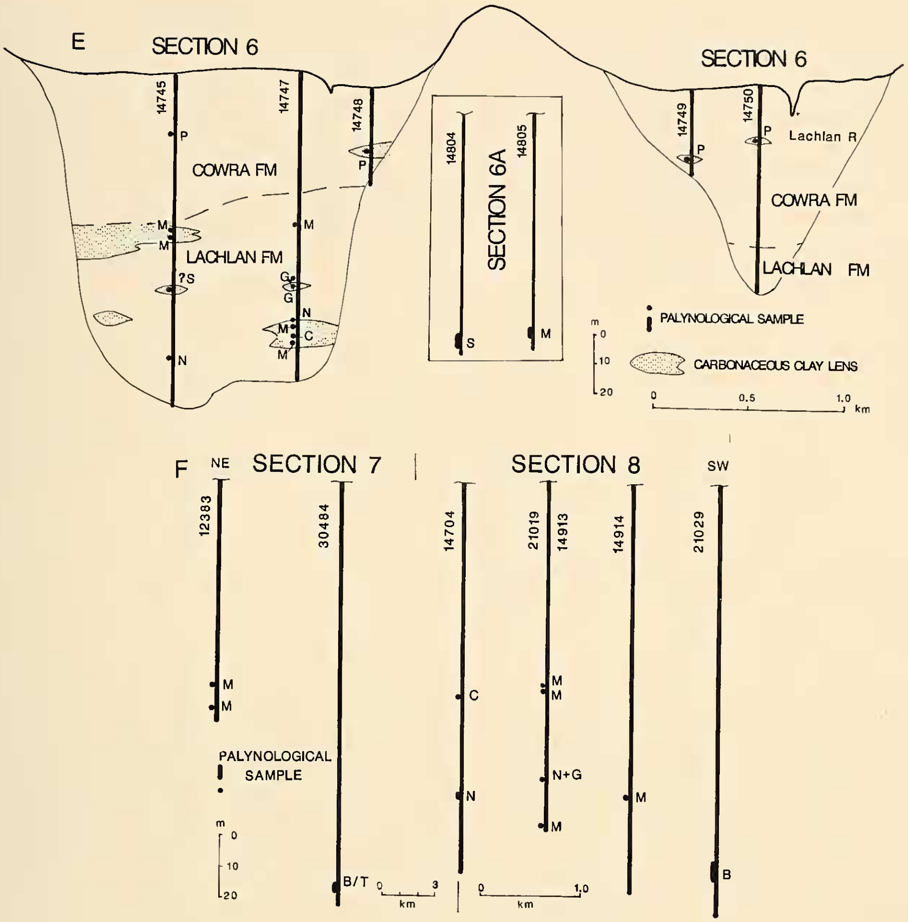

Fig. 16. The distribution of the palynological phases in sections across the valley. For location of the sections, see Fig. 2. Cross sections of valley, the distribution of carbonaceous clays and the boundary between the Lachlan and Cowra Formations from maps supplied by the Department of Water Resources. Only those bores yielding pollen are included. Legend: P — Pleistocene; PP — Pliocene-Pleistocene transition; M — Myrtaceae phase; G — Gymnosperm phase; N — *Nothofagus* phase; S — High spore assemblage; C — High Casuarinaceae assemblage; B — *T. bellus* Zone; T — *P. tuberculatus* Zone.

In summary, the most conspicuous difference of the 'Pleistocene' assemblages when compared with those of the mid Miocene-Pliocene is the virtual absence of the rainforest element, the high Compositae content, moderate Gramineae content and lower diversity. The changeover to 'Pleistocene' assemblages is recognized in other river valleys and may be used for stratigraphy (Martin, 1979, 1980, 1981) but there is no direct evidence available for dating. Wood has been retrieved once from the Cowra Formation, but it is beyond the range of radio-carbon dating, i.e. older than 35,000 to 40,000 years (Williamson, 1986).

PALAEOVEGETATION

Interpretations of the Tertiary palaeovegetation from pollen assemblages rely on general principles rather than on direct comparison with some analogous, living vegeta-

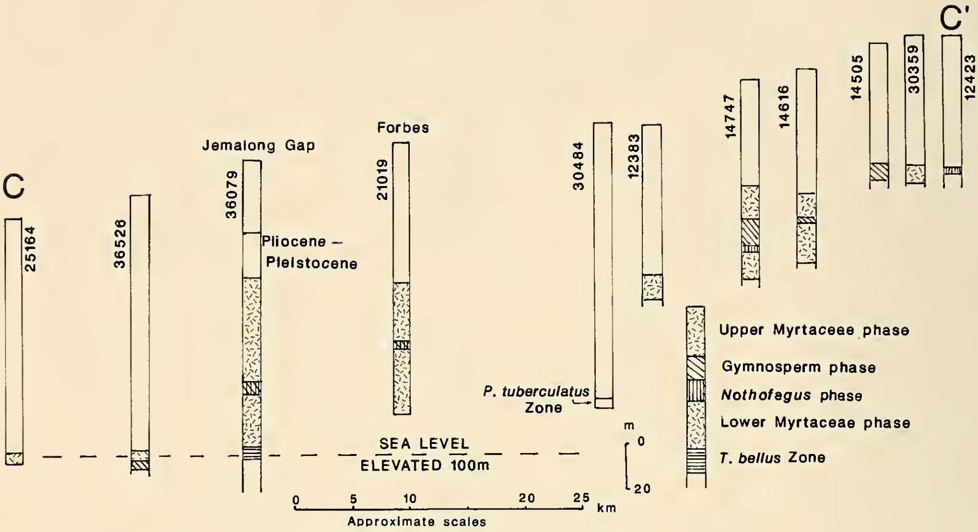

Fig. 17. Section C-C^1 running lengthwise of the Lachlan River valley.

tion. A good fit with some extant vegetation does not exist. For example, the three pollen types of *Nothofagus* are found together in the early—mid Tertiary assemblages but the living plants do not grow together anywhere in the world today. The *brassii* type only is found in New Guinea, New Caledonia and the New Hebrides, whereas the other two types may grow alone or together in southeastern Australia, Tasmania, New Zealand and South America. As a second example, *Dacrydium* and *Dacrycarpus* are found in New Guinea, New Caledonia and New Zealand today. In the early—mid Tertiary, the pollen is found with *Lagerostoma franklinii* which is restricted to Tasmania. Other examples could be given, but if a general, rather than a specific approach is adopted, floristically, comparable vegetation is found on the Australian mainland, Tasmania, New Zealand, New Caledonia and New Guinea.

Experiments with surface samples, in which the pollen assemblage on the ground is compared with the composition of the vegetation, show that changes in abundance of pollen may be interpreted as changes in abundance of the parent plant in the vegetation. For high pollen producing plants, deposition of pollen decreases exponentially from the source (Birks and Birks, 1980). An empirical value may be determined, values above which indicate local abundance of the parent plant (e.g. MacPhail, 1979). Low values may be interpreted as pollen transported in from a distance or a low occurrence of the parent plant in the vegetation. Little may be deduced about the abundance or rarity in the vegetation of low (percentage) pollen producers.

Assemblages which consist largely of tree pollen may be interpreted as closed forest (= rainforest). With a closed canopy, insufficient light reaches the ground to support a good cover of low growing, ground covering, herbaceous plants. With a good representation of the low growing plants, *viz.* Gramineae, Restionaceae, Cyperaceae and Compositae, the forest cover would have been more open. If values for these latter taxa are high, they may indicate woodland, savannah, grasslands or herbfields.

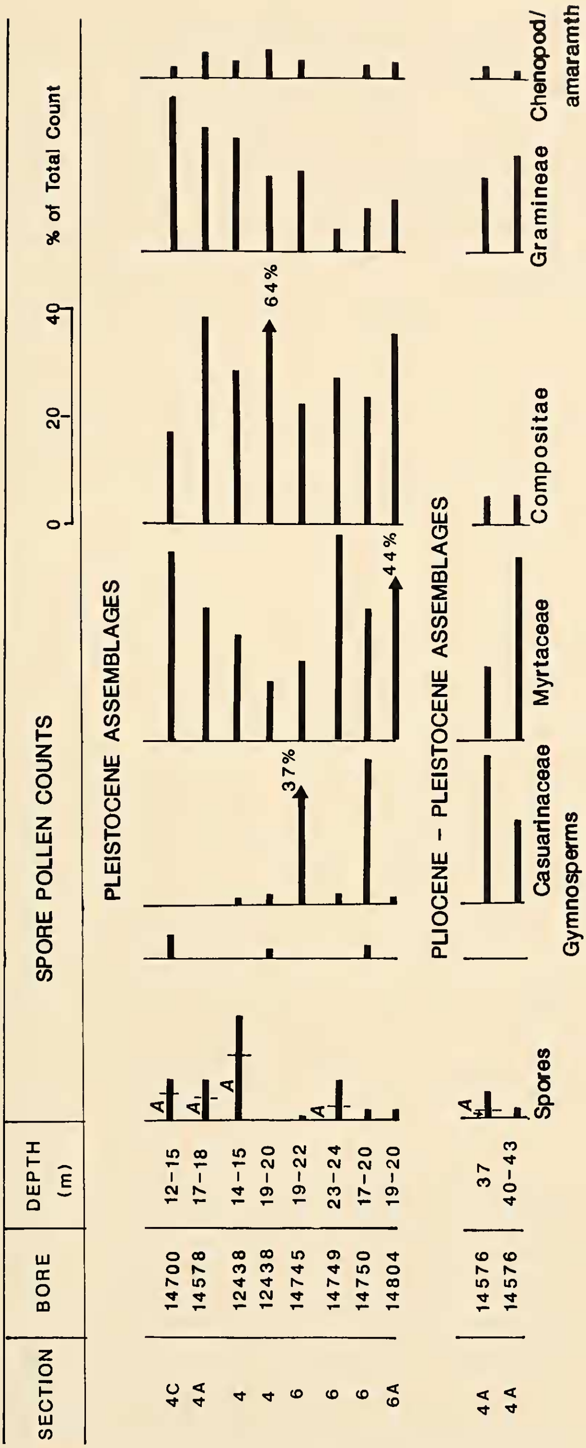

Fig. 18. Pleistocene and Pliocene—Pleistocene transitional assemblages. A, Anthocerotae.

Late Eocene to mid Miocene palaeovegetation

The vegetation throughout the whole of this period of the Tertiary must have been closed forest, judging by the extremely low content of the light-demanding, low-growing plants (see Fig. 9 and the *T. bellus* Zone in Figs 10 and 11). The *brassii* type of *Nothofagus* was prominent from the late Eocene until the late Oligocene — early Miocene when it declined and Myrtaceae became the more abundant group. This changeover in the most abundant pollen group is thought to indicate a climatic change (discussed further below).

In the Murray Basin, *N. flemingii* was more abundant in some levels of the sequence, e.g. the 230m to 240m level in bore 36342 (Fig. 9). This greater abundance may be found anywhere in the Oligocene *P. tuberculatus* Zone, A and B subdivisions, as shown in Figs 7 and 8. It is thought that *N. flemingii* required a well-drained habitat (Martin, 1984a; 1986a; 1986b) and the Lachlan region of the basin, with its slightly shallower and rather irregular basement (see Fig. 7) provided more of this habitat than the Murrumbidgee area (Martin, 1984b). Thus there was a forest mosaic, with *N. flemingii* common on well-drained sites and the *brassii* type of *Nothofagus* prominent elsewhere. This mosaic would change with time, according to changes in the course of the rivers and sedimentation. Deposition of sands with the resulting good drainage would favour *N. flemingii*.

The Myrtaceae which became prominent in the late Oligocene-early Miocene, is a heterogeneous group. The 'eucalypt type', *Myrtaceidites eucalyptoides*, which conforms with the *Angophora* — bloodwood eucalypt morphology is present but not common. Recent work shows that some species of eucalypts have pollen which is much smaller and generally unlike that of the *Angophora* — bloodwood eucalypt type (Chalson and Martin, manuscript submitted). Most of the myrtaceous pollen is generally similar to that of *Acmena*, *Baeckea*, *Backhousia*, *Syzygium*, *Tristania* and probably others as well (Martin, 1978). *Decaspermum*, *Austromyrtus* and *Rhodamnia* may be present during this time also (Truswell *et al.*, 1985). Whatever the affinities of this pollen, the very low content of ground covering plants indicates that the myrtaceous-dominated vegetation was closed forest.

The proteaceous component of the vegetation in the late Eocene may have been substantial. A number of these proteaceous types (*Proteacidites* spp.) became extinct about the end of the Eocene and during the Oligocene, but other types, e.g. *Helicia* — *Orites* are found throughout the whole period (see Appendix 2). Proteaceae pollen is under-represented in surface pollen spectra. In *Eucalyptus* forest with s sclerophyll shrub layer in which species of Proteaceae may constitute the major part, the pollen registers in low percentages only (Martin, 1978). Tree species of Proteaceae may be widespread in northeastern Queensland rainforests but their pollen is found only in low percentages in surface samples and Quaternary deposits (Kershaw, 1970b). It is thought that the ancient proteaceous types may have been higher pollen producers with more efficient pollen dispersal (Martin, 1978). A change in the pollination mechanism of the family Proteaceae is proposed by A. R. H. Martin (1981).

Diversity increases in the early Miocene C subdivision of the *P. tuberculatus* Zone, particularly amongst the tricolpate-tricolporate group. Quantitatively these account for an increase of only a few percent, from 7-9% in the Oligocene to 14-18% in the latter. Given that the parent plants would have been low pollen producers, they could have been quite significant in the vegetation. The proteaceous group, low pollen producers also, increase somewhat in the early Miocene as well (discussed previously). Collectively, these low pollen producers may have formed a substantial portion of the vegetation.

As discussed previously, early Miocene silicified woods in the upper Lachlan have been identified as Myrtaceae with affinities to *Eucalyptus* B, *Acacia* and *Nothofagus* (Bishop and Bamber, 1985). This wood assemblage cannot be placed in any palynological zone, but it further illustrates the mixed nature of the vegetation.

The mid Miocene *T. bellus* Zone vegetation would have been generally similar to that of the C subdivision, with a slight change in species composition.

?Mid Miocene-Pliocene palaeovegetation

The botanical affinities of the Myrtaceae pollen group of the Pliocene sequence is not necessarily the same as that of the group in the late Oligocene-early Miocene. Both the *Angophora* — bloodwood eucalypt type and the small-grained eucalypt type (discussed previously) are present. Other types similar to *Austromyrtus*, *Baeckea*, *Backhousia*, *Rhodamnia*, *Syzygium*, *Tristania* (Martin, 1973a) and possibly others as well are present. Whatever the identity of the Myrtaceae pollen, its association with some rainforest element (see Appendix 3) and low Gramineae/Compositae counts (see Figs 10, 11, 12) indicate a good forest cover.

The Myrtaceae phase may have been closed forest (Martin, 1978) and this interpretation would accommodate the rainforest element present in the Myrtaceae phase. However, tall open forest (= wet sclerophyll), in which species of eucalypts are dominant and some rainforest taxa are present as small trees (Ashton, 1981) is an alternative interpretation. The rainforest element present in wet sclerophyll includes myrtaceous taxa. Moreover, tree ferns are a conspicuous feature of the east coast wet sclerophyll (Ashton, 1981) and these assemblages have a considerable *Cyathea* spore content. The nature of the myrtaceous forests is considered further in the discussion.

The gymnosperm and *Nothofagus* phases would have been closed forests. It is likely that they had a patchy distribution, occupying the well-watered sites in the valley. Myrtaceous forests were present also, although probably relegated mainly to drier sites, the slopes and ridges. *Nothofagus* was more extensive upstream near Cowra, with a noticeable decline downstream, with very little at Jemalong Gap (see Fig. 13). This distribution suggests that *Nothofagus* migrated downstream from the highlands where it was probably considerably more abundant during the late Miocene. Gymnosperms were most abundant upstream also, but they were relatively common downstream as well, to beyond Jemalong Gap (see Fig. 17). *Podocarpus* was the most common gymnosperm but Cupressaceae, *Phyllocladus* and *Dacrycarpus* were sometimes abundant (see Fig. 14). Today, *Callitris* of the Cupressaceae is well known in the inland, semi-arid regions and may grow as forests in the Lachlan Valley, but there is one rainforest margin species, *Callitris macleayana* (Boland *et al.*, 1984). There are other possibilities within the family Cupressaceae. Whatever the identification of the fossil Cupressaceae pollen, its association with other rainforest taxa and a carbonaceous clay lens (indicative of a swampy environment) suggests that it was a rainforest taxon also.

Other rainforest angiosperms (see Appendix 3) were usually present. The pollen registers in low percentages, but the parent plants may have been relatively common. They may have occupied favourable habitats such as stream sides and sheltered gullies, or may have been present in the understorey layers of wet sclerophyll.

As discussed previously, a more specific identification of Casuarinaceae pollen is difficult. *Gymnostoma* may be found in rainforests. *Casuarina* is not a normal constituent of rainforest but it may be found in open forest bordering rainforest. Species of *Casuarina* may be found in most kinds of vegetation, from coastal open forests to arid shrublands. However, the high Pliocene Casuarinaceae assemblages occur stratigraphically close to the *Nothofagus* and gymnosperm phases, hence they may represent rainforest taxa or taxa which border rainforest. Riparian species may have been involved. The group may have consisted of different taxa at different times.

A shrub or small tree element may be present also (see Appendix 3). Most of the taxa in this element are represented by only a few percent and little may be deduced about their abundance. In a study of surface samples, Ladd (1979) did not recover *Acacia* pollen, yet

Acacia was co-dominant in the vegetation beneath which the samples were taken. Thus taxa in this element may have been common in the vegetation.

Fern spores are subject to water transport (Ladd, 1978; Birks and Birks, 1980). Consequently, the high spore assemblages may have been produced by runoff from a nearby gully containing abundant ferns. Such gullies would be particularly favourable for *Cyathea.*

Towards the top of the upper Myrtaceae phase, Compositae and Gramineae increase and the gymnosperms and other rainforest taxa decrease. These assemblages are thought to be transitional between the Pliocene and Pleistocene. The closed forest canopy was decreasing and open forest, woodland and grasslands were expanding.

In summary, the ?mid Miocene — Pliocene sequence is a record of gradual decline of the rainforest element. It was moderately common in the oldest part of the sequence. The vegetation was probably a mosaic of rainforest in the most favourable habitats, wet sclerophyll (further evidence for wet sclerophyll is presented in the section on fire history) covering considerable areas and with dry sclerophyll in the driest habitat. For a period, probably in the early Pliocene, rainforest expanded and would have occupied substantial areas of the valley during the *Nothofagus* and gymnosperm phases. Subsequently in the upper Myrtaceae phase, the rainforest element declined and eventually disappeared from the Lachlan Valley and its tributaries.

Pleistocene palaeovegetation

The abundance of Compositae and Gramineae (see Fig. 18) indicates open vegetation, probably woodland and grasslands/herbfields. Most of the trees would have been myrtaceous or casuarinaceous. The Casuarinaceae group, which is sometimes abundant, probably consisted of different species to those in the group during the late Miocene — Pliocene. Gymnosperms were rare and rainforest angiosperms (see Appendix 3) had disappeared from the valley and its tributaries.

The spore content is low and Anthocerotae are the most common of the group. Anthocerotae are commonly found along stream banks in open vegetation.

The Pleistocene sequence is very disjointed and nothing may be deduced about the vegetation of glacial and interglacial times. The stratigraphic position of the assemblages in the Cowra Formation (see Fig. 16) suggests most of them may be contemporaneous. It is thought these assemblages are older Pleistocene in age. It may be argued that the interglacials were more humid, being times of high sea level, and swamps necessary for preservation of pollen would be more likely at these times, hence all of the pollen assemblages presented here probably represent interglacial period(s). However, there is no direct evidence to support this argument. These Pleistocene assemblages are presented here for comparison with those of the Pliocene and to illustrate the considerable difference between the two.

Wood has been encountered in bore 12437, Section 4 at a depth of 26m (see Fig 16). It has been identified as probably *Eucalyptus resinifera* by H. K. Bamber, Forestry Commission (Williamson, 1986). *E. resinifera* is found in dry sclerophyll and wet sclerophyll (Boland *et al.*, 1984). Unfortunately, pollen was not recovered from this level in bore 12437. The identification of *E. resinifera* suggests that some relatively denser forest vegetation may have been present in the Pleistocene, probably confined to the more favourable habitats.

FIRE HISTORY

Black carbonized particles are readily recognized in palynological preparations. Such particles are usually regarded as charcoal fragments and variations in abundance of the particles are used to reconstruct Quaternary fire history (e.g. Singh *et al.*, 1981). Carbonized particles, or fusinites of the coal petrologist, may result from charring, oxidation, mouldering or fungal attack before deposition, or on the peat surface. Carbonization may also result from coalification after deposition (Teichmuller, 1982). Thus care must be exercised in the interpretation of carbonized particles, particularly for the Tertiary and older geological periods.

Fire is not essential for carbonization of plant material. It is thought that dehydration and oxidation on the swamp surface may produce fusinite. Fungal attack may cause effects similar to carbonization. For example, dry rot alters the unused part of the wood into carbon-rich, humic substances. Other fungi and other plants may produce dark material, which looks similar to carbonization. These and other factors are reviewed by Teichmuller (1982). By and large, these processes which produce carbonization without burning are not well understood, but there seems little doubt that a portion of this material may be attributed to burning (Kemp, 1981).

The re-working of carbonized particles in older sediments, particularly if they contain coal seams, may cause serious error in the deduction of a fire history. However, re-working may be detected by older palynomorphs included in a younger assemblage. A very small amount of early Tertiary re-working has been detected in the late Miocene — Pliocene sequence of the Lachlan River Valley, but no Cretaceous or older palynomorphs have been found. In particular, there is no evidence at all of re-worked Permian coals, the most likely cause of serious error. There may be a very small amount of Early Cretaceous re-working in the base of the Eocene — Oligocene sequence of the Murray Basin.

When fire is the cause of carbonization, a high degree of charring may result in very brittle fusinite which readily disintegrates into fine fragments. Less strongly charred wood may preserve the cellular structure, although probably with distortions (Teichmuller, 1982). Much of the fuel in forests is bulky and rarely, if ever, burns completely (Luke and McArthur, 1978). Fires may sweep over herbaceous swamps, burning the plant cover to water level. Fusinites of such peats shatter easily and are deposited as fine splinters. The surface of a peat swamp may occasionally dry out and ground burning may occur with the formation of a great deal of ash. This ash, however, is easily blown away or dissolved in swamp waters which are rich in carbon dioxide. Some charcoal remains on the ground, but the fine fragments are readily blown away and deposited elsewhere (Teichmuller, 1982). These are a few of the possible effects in the deposition of carbonized particles that may result from fires.

Clark (1984) reviews the effects of different pollen preparation procedures on carbonized particles and the problems of identification. The most important for this study, which presents counts of carbonized particles, is that larger particles may be broken into small pieces. Burning destroys the stratification of the cell wall (middle lamella, primary wall and secondary wall) and this feature may be used to identify charcoal from dark-coloured, unburned plant tissue (Cope and Chaloner, 1980). However, different chemical treatments may destroy stratification or produce a similar effect in cell walls which have had stratification destroyed (D. R. Selkirk, *pers. comm.*). In this study, carbonized particles were counted in preparations made for palynomorphs where treatment included a moderate oxidation process. Identification of particles was made with reference to burnt plant material which was then treated by the same chemical procedure as that used on the sediments. Particles within the size range of pollen were counted. Estimations of the area of carbonized particles (Clark, 1982) which allow for the different sizes of the particles were not possible as the preparations were made long before the decision to count carbonized particles and the methods used are unsuitable for area estimations. Counts are presented as the ratio of carbonized particles to total pollen count, in Fig. 19.

The interpretation of the abundance of carbonized particles is problematical (see review by Clark, 1983), even with the assumption that most of the particles result from burning. Charcoal particles may be transported by air currents, particularly at the time of fire, or washed from bare ground after fires. Larger particles may be broken into smaller fragments before deposition. A greater abundance of charcoal does not necessarily mean more fires, it may result from bigger fires. More charcoal probably indicates that more fuel was burnt, but even this interpretation assumes that the fuel was charred to the same degree.

The prerequisites for wild fires are

1. a fuel supply;
2. the fuel must dry out sufficiently so that it can burn; and
3. a source of ignition.

Lightning would have been the main agent (Kemp, 1981), and probably the sole source of ignition for the Tertiary and the portion of the Pleistocene under consideration here, which predates the arrival of man.

The palaeovegetation was almost entirely forests, with woodlands and grasslands becoming prominent only in the Pleistocene. Fuel is not limiting in forests (Luke, 1961). Closed forests rarely burn, except in drought periods when they are subjected to exceptional drying (Webb, 1970; Luke and McArthur, 1978). However, the pollen record is biased towards those plants growing close to the site of deposition. It may be that closed forest grew around the site of deposition and was rarely burnt, whereas a drier, more open kind of vegetation on the slopes and ridges was burnt more frequently, the charcoal being transported eventually to the site of deposition.

The interpretation adopted in this study is that an increase in carbonized particles, most of which are probably charcoal, indicates a greater frequency and/or intensity of dry periods which would allow burning, given adequate fuel. The major control of wild fires is thought to be climatic (discussed further below). Charcoal from fires anywhere in the catchment would eventually become incorporated in sediments at the site of deposition.

Counts of carbonized particles are presented in Fig. 19. In the late Eocene — early Miocene of Bore 38342 (Fig. 19A), the ratios of carbonized particles are low but increase somewhat towards the top of the sequence. In this sequence, there is a variety of dark-coloured bodies, some of which may result from the coalification process, but only particles similar to the reference burnt plant material and to the carbonized particles seen in the late Miocene — Pliocene sequence were counted.

The abundance of carbonized particles in the mid Miocene *T. bellus* Zone at Euabalong and Jemalong Gap is comparable to the early Miocene in the top of Bore 36342. In the Myrtaceae phase of the late Miocene — Pliocene sequence, the abundance is much higher. The ?*Nothofagus*-gymnosperm phase of Jemalong Gap has lower ratios of carbonized particles which are comparable with those of the *T. bellus* Zone. In Bore 14747, the *Nothofagus* phase has low ratios and the ratios of the gymnosperm phase are intermediate between the *Nothofagus* and Myrtaceae phases.

In summary, burning levels were extremely low in the late Eocene and most of the Oligocene. In the late Oligocene to mid Miocene, burning increased somewhat but it was still relatively low. Burning increased considerably in the lower Myrtaceae phase (which may be as old as mid Miocene). Burning decreased in the *Nothofagus* and gymnosperm phases (probably early Pliocene) to levels similar to those of the Oligocene — mid Miocene and increased in the upper Myrtaceae phase to the highest levels of the sequence.

THE EFFECTS OF CHANGING SEA LEVEL

Changes in sea level have an important influence on sedimentation and the environment, especially close to the shoreline. At times of high sea level, drainage is sluggish and the low-lying areas in the landscape are swampy. Sediments accumulate at these times. Evaporation is higher from the shallow seas over the continental shelves and flooded low-

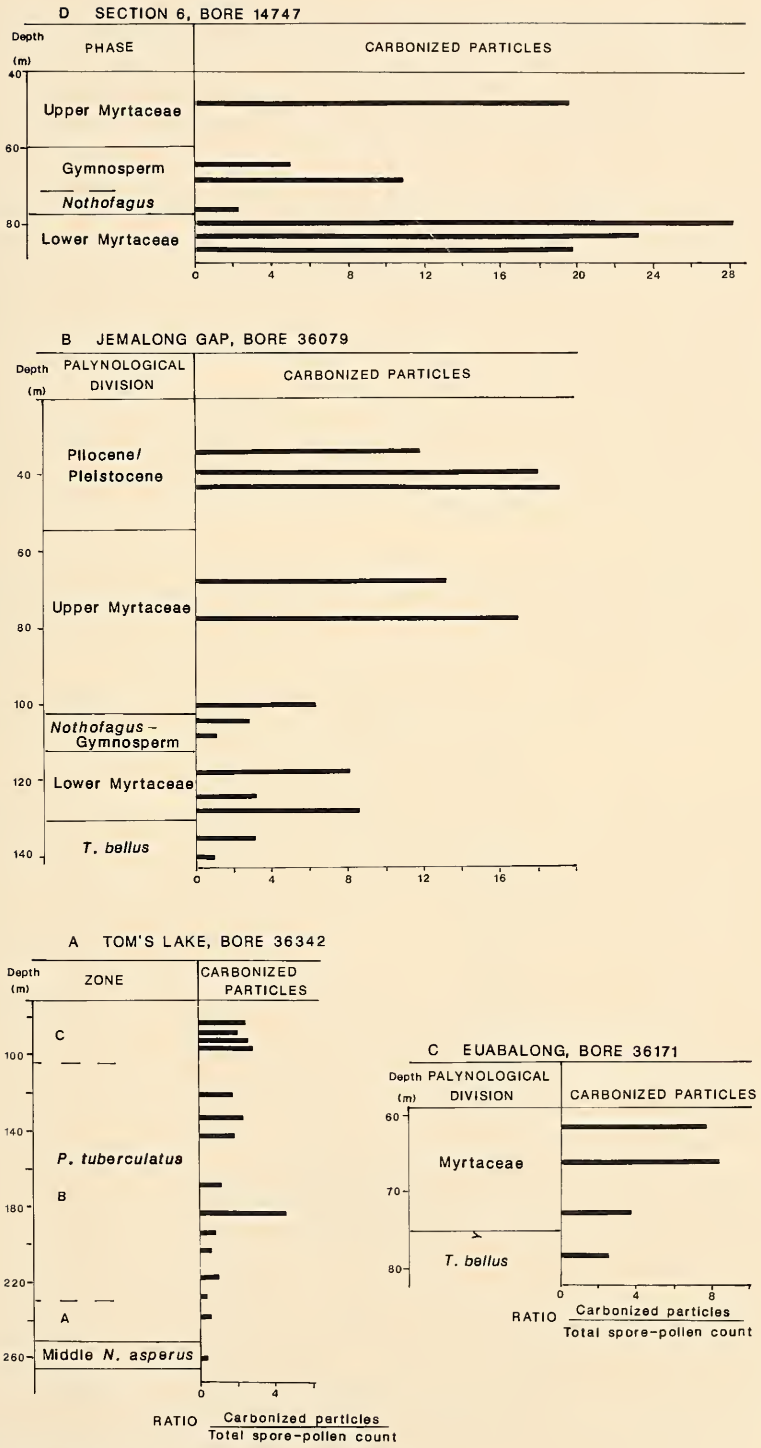

Fig. 19. Carbonized particle counts.

lying areas. As a consequence, precipitation is greater and through this effect, changing sea levels may have considerable influence a long way from the shoreline. At times of low sea level, with the shoreline close to the edge of the continental shelf, drainage is more efficient and there may be erosion and/or lack of sedimentation. Evaporation from the colder, deeper seas at the edge of the continental shelf is less, consequently precipitation is lower. At these times, the climate is more continental.

Fig. 20 presents the late Eocene to Oligocene changes in sea level, based on the sedimentary cycles recognized on the southern margin of Australia (from Loutit and Kennett, 1981). This curve is the most appropriate, for although the changes in sea level may be correlated on a worldwide basis, local tectonics may modify their expression. Sedimentary cycles have not been reported for the late Pliocene to Pleistocene on the southern margin of Australia so the global changes in sea level (from Vail *et al.*, 1977) are presented for this time range. The changes became more frequent in response to glacial-interglacial oscillations of the last 2-3 million years.

In Bore 30407 of section A-A[1] (see Fig. 7), the younger *P. tuberculatus* Zone extends almost 60m below the boundary of the older Middle *N. asperus* Zone. This depth of 60m is considerable and more than would be expected with a simple change of the river course. It is thought to illustrate downcutting at a time of low sea level and subsequent fill with younger sediments.

In the eastern edge of the Murray Basin, the Oligocene low sea level (Fig. 20) is expected to be a time of erosion. However, the effect of this low sea level is not detectable in the non-marine sediments (R. M. Williams, *pers. comm.*). It is thought that with the almost

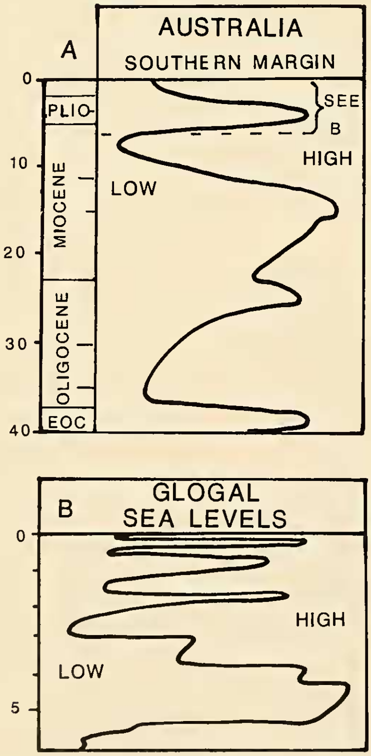

Fig. 20. Changes in sea level. The southern margin of the Australian continent from Loutit and Kennett (1981) and global sea levels from Vail *et al.* (1977).

flat terrain and a rainfall sufficiently high to maintain the forest cover, erosion would be minimal (Bishop, 1985b; Martin, 1986a; 1986b). The late Miocene low sea level, however, is evident in the sediments (R. M. Williams, *pers. comm.*). At this time, the climate was becoming drier and the cover of vegetation would be more difficult to maintain, thus allowing erosion (Martin, 1986a; 1986b). The relative scarcity of the mid Miocene *T. bellus* Zone which was deposited at a time of high sea level, may be attributed to subsequent erosion during the late Miocene low sea level.

The lower Myrtaceae phase is not as thick as would be expected if, as discussed previously, it begins in the mid Miocene. It is thought that the late Miocene low sea level, accompanied by a somewhat drier climate (discussed further below) resulted in erosion or lack of deposition and this may account for the relatively thin sections of lower Myrtaceae phase seen in Figs 10, 16 and 17. Other factors may be involved as well. Tectonics may have had some influence in the Lachlan River Valley where lower Myrtaceae phase forms a relatively thin section over the basement. As discussed previously, there is also uncertainty about the age of the transition of the *T. bellus* Zone and lower Myrtaceae phase (see Fig. 5).

The early Pliocene high sea level is expected to be a time of higher precipitation which, it is thought, allowed the *Nothofagus* and gymnosperm phases in the Lachlan River Valley. With the subsequent fall in sea level in late Pliocene, the Myrtaceae phase is evident once more.

The relatively rapid rise and fall of sea level in the Pleistocene cannot be detected in the palynological record which, as discussed previously, is extremely fragmentary. Moreover, the sea was denied access to the Murray Basin by the closure of the entrance, probably in the late Pliocene (Brown *et al.*, 1968; Abele *et al.*, 1976). As a consequence, the drainage route to the sea became much longer and this would have made a difference to the erosion/sedimentation associated with low/high sea levels (respectively).

PALAEOCLIMATE

The palaeoclimate may be deduced from the climatic requirements of comparable, present-day vegetation, but this can only be attempted at a very general level. Interpretations of the palaeovegetation are very general and as discussed previously, a good fit with some extant vegetation does not exist. However, some general climatic parameters may be deduced from the extant vegetation and applied to the palaeovegetation to illustrate climatic trends.

Brassii species of *Nothofagus* may be dominant in the mid montane zone of the New Guinea Highlands (Johns, 1982). *Nothofagus* is generally associated with high precipitation of 1500-1800mm and considerable cloudiness which reduces light intensity and maintains high humidities. It is generally absent from areas which suffer a regular and sustained water deficit (Ash, 1982). In New South Wales, one species of the *menziesii* type, *Nothofagus moorei* is present in the Eastern Highlands and may be dominant where precipitation exceeds 1800mm. It is usually restricted to sites that are commonly fog bound (Baur, 1957). Boland *et al.* (1984) give the annual rainfall of *N. moorei*, not necessarily dominant in the vegetation, as 1500mm, with the driest months receiving 60mm, augmented by mountain mists. In general, *Nothofagus* requires a high precipitation and maintenance of relatively high humidities throughout the year.

As discussed previously, the myrtaceous vegetation may have been closed forest. In New South Wales, Myrtaceae are common in rainforests which require a precipitation of 1500mm for widespread development (Baur, 1957). Alternatively, the myrtaceous vegetation may have been wet sclerophyll (or mosaic of rainforest and wet sclerophyll) and the fire history favours this interpretation. Wet sclerophyll may be found over large tracts receiving between 1000mm and 1500mm (Ashton, 1981). Thus the Myrtaceae phase probably indicates a precipitation of somewhat less than 1500mm, probably between 1000mm and 1500mm.

The disappearance of the rainforest element from the landscape is another important parameter. The lower precipitation levels of the major eucalypt species of the drier end of the range of wet sclerophyll (in Ashton, 1981) is about 500-700mm (precipitation requirements from Boland *et al.*, 1984). The limit of subcoastal rainforest pockets across northern and northeastern Australia falls between the 600mm and 800mm isohyet (Webb and Tracey, 1981). Whichever interpretation of the Myrtaceae phase is favoured, it makes little difference to the climatic parameter at the drier end of the range.

Using these parameters and the trends shown by the carbonized particles, changes in climate may be reconstructed. It should be emphasised that there is no great precision in this reconstruction: the parameters are used more to illustrate a climatic trend.

In the Hillston region, the precipitation of the late Eocene and Oligocene was high, probably above 1800mm. High humidities were maintained throughout the year and the vegetation rarely dried out sufficient to allow burning. Fires would have been very limited in extent. There may have been a gradual, slight decrease in precipitation during the upper part of the Oligocene. In the late Oligocene — early Miocene, precipitation was probably less than 1800mm but above 1500mm. There was no definite seasonal dry period and fires were only slightly more frequent than in the preceding period. This level was maintained into the mid Miocene *T. bellus* Zone.

In the Hillston region, pollen preservation ceased in the early Miocene. Pollen preservation requires permanently wet sites which remain wet long enough for burial to a depth below the influence of the fluctuating water table. The disappearance of permanently wet sites from the landscape would have been the result, in part, of climatic change over the region as well as of a decrease of water transported into the region by the river (discussed further below). Subsequently, the sites of pollen preservation were located upstream from the edge of the Murray Basin, particularly around Jemalong Gap and in the Lachlan River Valley to Cowra.

In the ?mid Miocene, i.e. the start of the lower Myrtaceae phase, there was a further drop in precipitation probably to somewhat below 1500mm, but not less than 1000mm. A well-defined seasonal dry period became established at this time, and burning became a regular event in the landscape. The drier slopes and ridges were probably most subject to burning.

In the early Pliocene, the time of the *Nothofagus* and gymnosperm phases, precipitation increased, probably to more than 1500mm but not more than 1800mm. The level of burning decreased. In the mid — late Pliocene, the precipitation decreased once again to about or below 1500mm and the level of burning increased as well. Precipitation continued to decrease so that at the end of the Pliocene, it was probably about 500mm-800mm.

Wood recovered from the base of the Pleistocene Cowra Formation, identified as probably *Eucalyptus resinifera*, indicates a precipitation of at least 800mm, the lower limit for this species. This evidence does not contradict the above deductions, which are at best very general, and given the lack of any evidence to date the 'Pliocene — Pleistocene' boundary.

The changes in precipitation are shown diagrammatically together with the major palynological events in Fig. 21.

Today, the mean annual precipitation for Hillston is about 140mm, Forbes 200m to 210mm and Cowra, 240mm to 250mm, respectively.

The climatic parameters discussed above have been deduced from plant growth and in this context, 'precipitation' is more precisely 'effective moisture'. Effective moisture includes both rainfall and water transported by the river systems (Martin, 1986b) and the latter was probably important in the maintenance of the permanently wet sites required for pollen preservation. The climatic change described above could not occur over the Lachlan

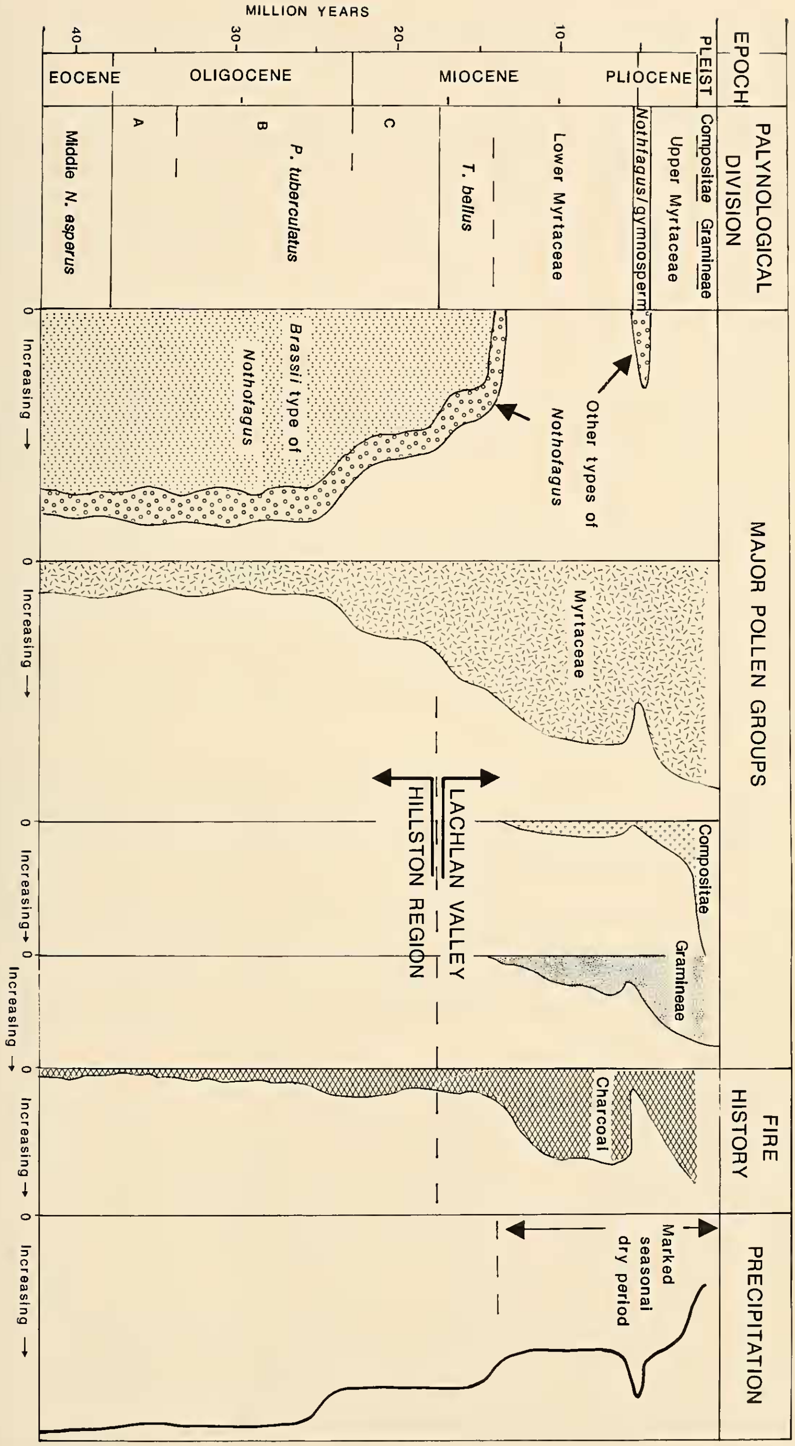

Fig. 21. Summary of major palynological events and the inferred changes in precipitation (Not to scale.)

Valley in isolation from the surrounding areas. Parallel changes would have occurred in the Eastern Highlands over the headwaters of the river and these would have been very important for the volume of water transported by the river.

Effective moisture also includes the influence of temperature through its effect on evaporation. Temperature is also very important for plant growth but it is not considered here because effective moisture is thought to be the major control. Oligocene — early Miocene temperatures were probably somewhat higher than those of today. Surface sea temperatures during the mid Miocene were about 5°C higher than those of today (Savin *et al.*, 1975; Shackleton and Kennett, 1975), hence land temperatures were probably somewhat higher also (Martin, 1986b).

DISCUSSION

The nature of the late Miocene — Pliocene myrtaceous forests with its component of rainforest taxa has long been problematical. It was thought that they were closed forests, perhaps akin to the 'heath forests' of Borneo (Martin, 1982). This interpretation was based on an inadequate appreciation of the diversity of pollen types within the genus *Eucalyptus*. With a greater eucalypt content, an alternative interpretation of wet sclerophyll forest is possible. The record of carbonized particles is extremely important in this context. Rainforest rarely burns (Webb, 1970; Luke and McArthur, 1978) whereas 'there can be little doubt that fire is an integral part of the environment' of wet sclerophyll forests (Ashton, 1981). The great increase in carbonized particles in both the lower and upper Myrtaceae phases supports the interpretation of wet sclerophyll forest. As discussed previously, the late Miocene — Pliocene palaeovegetation was probably a mosaic of rainforest, wet sclerophyll and dry sclerophyll, each type of vegetation occupying the appropriate habitat in the landscape.

A more precise identification of myrtaceous pollen is possible. The grain may be scored for a number of characters and a combination of several character states may be distinctive. It is found that the character states of the fine detail are the most promising for this purpose (Chalson and Martin, manuscript submitted). Taxonomically closely related species may not be separable (Martin and Gadek, manuscript submitted), but pollen of the family should be divisible into a large number of groups. A more precise identification of the pollen awaits the compilation of a reference set scored for the distinctive character states. For the late Miocene — Pliocene assemblages, this set should include all species common in eastern Australian rainforests, wet sclerophyll and dry sclerophyll — a formidable task. For older assemblages, the reference set should include species in New Guinea, New Caledonia and New Zealand.

Late Oligocene — early Miocene assemblages from the western Murray Basin have a considerable myrtaceous content (Truswell *et al.*, 1985) but it should not be assumed this content is the same as that of the late Miocene-Pliocene assemblages in the Lachlan valley. A study of the carbonized particles may shed some light on this problem, but more precise identification of the myrtaceous pollen is required for the western Murray Basin also.

The major changes of palaeoclimate, as inferred from the vegetation, are thought to be linked with the development of circum-Antarctic oceanic circulation and the extent of glaciation on Antarctica (Martin, 1986b). Antarctica has had, and still has, a profound influence on world climate (Flohn, 1978), particularly on Australia because of its close proximity. About late Oligocene, circum-Antarctic circulation was established (Kennett, 1977; 1978). This factor probably reduced the efficiency of the heat transfer from the equator to the pole, thus increasing the temperature gradient between these regions. The extent of ice cover on Antarctica is uncertain but all the evidence indicates high latitude cooling and a northwards shift of westerly winds which would have influenced much of southern

Australia (Kemp, 1978; Flohn, 1978). It is thought that these events initiated the decrease in precipitation which resulted in the decline of the *brassii* type of *Nothofagus* (Martin, 1986b).

The early Miocene was a time of increasing temperatures (Savin *et al.*, 1975; Shackleton and Kennett, 1975). At the beginning of the mid Miocene, a major global climatic threshold was reached with the development of the East Antarctic ice cap (Kennett, 1977; 1978). The cause of this event remains unknown, but Kennett (1978) notes that this development occurred at a time of warmer temperatures which would have increased precipitation over Antarctica. (The mid Miocene was a time of high sea level, as discussed previously.) By the late middle Miocene, temperatures began to fall again. In the late Miocene, the ice cap retreated somewhat. It is difficult to match up the complex, poorly-dated events in the Lachlan River region with the complex developments in Antarctica. However, the mid Miocene was a time of profound change in both, and in this respect, they are in agreement. The late Miocene was a time of major cooling (Savin *et al.*, 1975; Shackleton and Kennett, 1975). Cooler oceanic temperatures result in lowered precipitation and this is in accord with the lower Myrtaceae phase of this time and the inference of reduced precipitation.

The charcoal record suggests that a well marked dry season, which allowed fires to become an integral part of the environment, dates from the ?mid — late Miocene.

A major extension of the Antarctic ice cap occurred in the late Miocene — early Pliocene (Kennett, 1977), a time of somewhat higher temperatures (Savin *et al.*, 1975) and high sea levels. This is thought to coincide with the *Nothofagus*/gymnosperm phases. Cooling continued from the mid Pliocene (Kennett, 1977; Savin *et al.*, 1975) which would have resulted in lower precipitation and the return of the Myrtaceae phase. A further global climatic threshold was passed in the late Pliocene when the glacial/interglacial oscillations commenced (Kennett, 1977). It is thought that this event coincided with the elimination of the rainforest taxa from the Lachlan River valley.

Climatic changes such as these could not .have occurred over the Lachlan valley in isolation from the surrounding areas which must have experienced similar or parallel changes. There is evidence of a climatic gradient across the Murray Basin, parallel to that of today, during the late Oligocene — mid Miocene (Martin, 1986b).

Decreasing precipitation over the Eastern Highlands would have had extremely important consequences on the activity of the rivers. The mid Miocene decrease in precipitation would have reduced the volume of water carried by the river such that it was unable to maintain the permanently wet sites in the Hillston region, but it was sufficient to maintain some permanently wet sites upstream in the Lachlan valley.

Weathering subsequent to deposition may destroy pollen and this may alternatively account for lack of pollen preservation. However, it is unlikely to be the sole cause. In the Hillston region, pollen preservation ceases in the early Miocene and the upper 80-100m of sediment are barren. In the Cowra district, however, grey carbonaceous clays containing Pleistocene assemblages may be found at depths of less than 20m. Thus the observed pattern of the cessation of pollen preservations being younger, further upstream best fits an hypothesis of a climatic gradient and a progressively diminishing volume of water carried by the river.

Changing sea levels and climate have probably played a part in shaping the Lachlan valley itself. As discussed previously, the late Miocene low sea level was a time of erosion and this would have removed most of the older sediments in the valley. Early and mid Miocene sediments are only found south of the present river near Forbes (see Figs 2 and 16F). The river once turned southwest about Section 7 and passed under Section 8, some 15km southwest of Forbes (discussed previously). When base levels were lowered and downcutting commenced, it is likely that the river adopted its present, shorter course to Jemalong Gap, thus bypassing the older sediments to the south.

The late Miocene was also a time of reduced precipitation hence the river carried a reduced volume of water which would have cut a narrower valley within the existing wide valley to produce the observed valley-in-valley structure. Williamson (1964; 1986) argues that the valley-in-valley structure was produced as a result of uplift of the highlands but Bishop *et al.* (1985) note that there does not seem any need to invoke dynamic (active) tectonism to account for the geomorphology of the Lachlan Valley. However, isostatic rebound (i.e. passive tectonism) probably occurred in response to erosional unloading (Bishop, 1985b). Moreover, signs of minor isostatic uplift may be expected mostly at the edges of the highlands (Bishop, 1987). Earthquakes in the region today show that adjustment to stresses in the earth's crust is still in progress (Denham *et al.*, 1985). Thus passive tectonism, combined with a reduced precipitation probably produced the valley-in-valley structure.

Climate has probably had an influence on the nature of the sediments themselves. With a high precipitation, various rock types would be decomposed leaving only the most resistant quartz and chert, as seen in the Lachlan Formation. The Cowra Formation, which contains an assortment of the rock types found in the catchment area, was deposited under much lower precipitation: insufficient for their decomposition. As discussed previously, Williamson (1986) postulates a formerly widespread quartz gravel formation as the source of the quartz in the Lachlan Formation. No doubt, older sediments have been reworked and they were probably mainly quartz. An hypothesis about the source of the quartz sands and gravels in the Lachlan Formation would have to be suitable for a very wide application, for all the Pliocene and older sediments of the river valleys of the western slopes of New South Wales have similar quartz gravels and sands. Experience with sediments of Cretaceous to early Oligocene age in the Gippsland, Bass and Otway Basins (Martin, unpubl.) has revealed similar quartz sands and the almost complete absence of other resistant rock types. Precipitation was also higher throughout this time span. Thus it is thought that climate has been the major factor in the production of these quartz rich sediments.

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APPENDIX 1

THE POLLEN GROUPS

SPORE/POLLEN GROUP	FOSSIL NAME	PLANT TAXA
Anthocerotae	*Cingulatisporites bifurcatus* 1	Similar to Anthocerotae
Fern spores	Numerous	Numerous pteridophyte taxa
Cyathea	*Cyathea paleospora* 1	*Cyathea* spp
Gymnosperms	*Araucariacites australis* 1	Araucariaceae, mainly *Araucaria* but *Agathis* could be included
	Cupressaceae	Cupressaceae
	Dacrycarpites australiensis 2	*Dacrycarpus*
	Dacrydium florinii 1	*Dacrydium* spp
	Microcachryidites antarcticus 1	*Microcachrys*
	Phyllocladidites mawsonii 3	*Lagerostoma* (= *Dacrydium*) *franklinii*
	P. palaeogenicus 4	*Phyllocladus* spp
	Podocarpidites ellipticus 1	*Podocarpus*
Myrtaceae	*Myrtaceidites* spp	All taxa in the family Myrtaceae
Nothofagus	*Nothofagidites, brassii* group e.g. *N. emarcidus* 3 *N. vansteenisii* 3 *N. falcatus* 3	Species of *Nothofagus* growing in New Guinea, New Caledonia and New Hebrides
	Nothofagidites, fusca group *N. brachyspinulosus* 3 *N. flemingii* 3	*Nothofagus gunnii* and all New Zealand species except *N. menziesii*. Some South American species also
	Nothofagidites, menziesii group *N. asperus* 3	*Nothofagus moorei, N. cunninghamii, N. menziesii* and some South American species
Casuarinaceae	*Haloragacidites harrisii* 3 *Casuarinidites cainozoicus* 1	All species of the family. *Gymnostoma* cannot be separated from *Casuarina* on pollen morphology (see Kershaw 1970a).
Compositae	*Tubulifloridites* spp 1	All species in the family Compositae, excluding Cichorieae
Gramineae	*Graminidites media* 1	All species in the family Gramineae

THE POLLEN GROUPS (Cont'd.)

SPORE/POLLEN GROUP	FOSSIL NAME	PLANT TAXA
Cichorieae	*Fenestrites* sp. 5	Cichorieae of the family Compositae
Chenopod/amaranth	*Chenopodipollis chenopodeaceoides* 5	Family Chenopodiaceae and some taxa of the Amaranthaceae
Proteaceous type	*Proteacidites* spp (sens. lat.)	Mainly related to Proteaceae (excluding Banksieae and *Beauprea*)

References:
1. Martin 1973a
2. Cookson & Pike 1953
3. Stover & Partridge 1973
4. Cookson & Pike 1954a
5. Truswell *et al.* 1985.

APPENDIX 2

LOW PERCENTAGE ANGIOSPERMS IN THE EARLY– MID TERTIARY

These distributions apply specifically to the Lachlan River region and are not necessarily the complete range of the species

PLANT TAXON	FOSSIL NAME	OCCURRENCE Middle *N. asperus* Zone	*P. tuberculatus* Zone Subdivisions A + B	 C	 *T. bellus* Zone
Acacia	*Polyadopollenites myriosporites* 1			+	+
Anacolosa	*Anacolosidites* ssp 1	+			
Austrobuxus (Longetia)-Dissiliaria	*Malvacipollis* 1,5	+			
	Polyorificites oblatus 2,5 = *Heliciporites astrus* 1	+	+	+	+
Banksieae	*Banksieaeidites elongatus* 1	+	+	+	+
Beauprea	*Beaupreaidites* spp 1	+	+		
Compositae	*Tubulifloridites* sp 1			+	+
Cunoniaceae	Cunoniaceae (tricolporate) 3	+	+	+	
Cunoniaceae — Eucryphiaceae	*Geissois* — *Eucryphia* comp 3	+	+	+	
Cupanieae	*Cupanieidites* spp 1	+	+	+	+
Cyperaceae	Cyperaceae 2, *Cyperaceaepollis* spp 4	+	+	+	+
Dodonaea triquetra	*Nuxopollenites* sp 4			+	
Dodonaea spp	*Dodonaea sphaerica* 2		+		
Elaeocarpus	*Elaeocarpus* comp 3	+	+		
Epacridaceae	*Ericipites* spp 1	+	+	+	
cf Goodeniaceae	—				+
Gramineae	*Graminidites media* 2	+	+	+	+
cf *Grevillea*	—			+	
Haloragis	*Haloragacidites haloragoides* 2				+
Helicia — *Orites*	*Proteacidites ivanhoensis* 2	+	+	+	+
Ilex	*Ilexpollenites* sp 1	+	+		

Low Percentage Angiosperms in the early–mid Tertiary (Cont'd.)

		OCCURRENCE			
		Middle	*P. tuberculatus* Zone Subdivisions		
PLANT TAXON	FOSSIL NAME	*N. asperus* Zone	A + B	C	*T. bellus* Zone
cf Liliaceae	*Liliacidites* spp		+	+	
Loranthaceae	Loranthaceae 3	+	+		
Macaranga — Mallotus	*Tricolporopollenites endobalteus* 5	+	+	+	
Malvaceae	—		+		
Pelargonium	*Tricolporopollenites pelargonioides* 6		+		
Polygalaceae	*Polycolpites esobalteus* 1	+	+		
Proteaceae	*Proteacidites* spp	+	+	+	+
—	*Proteacidites rectomarginis* 1	+	+		
Quintinia	*Quintinia psilatispora* 2	+	+	+	+
'Randia' chartacea	*Triporopollenites bellus* 1				+
Restionaceae, *Hypolaena* type	*Milfordia hypolaenioides* 2	+	+	+	+
Restionaceae, *Restio* type	*Milfordia homeopunctata* 1	+	+		
Santalaceae	*Santalumidites cainozoicus* 1	+			
Sapotaceae	*Sapotaceoidaepollenites rotundus* 1	+	+		+
Sparganiaceae	*Sparganiaceaepollenites* spp 2	+	+	+	+
—	*Stephanocolpites oblatus* 2		+	+	+
Symplocos	*Symplocoipollenites austellus* 1				+
Tasmannia	*Drimys tetradites* 2				+

References:
1. Stover & Patridge 1973
2. Martin 1973a
3. Luly *et al.* 1980
4. Truswell *et al.* 1985
5. Martin 1974
6. Martin 1973b

APPENDIX 3

LOW PERCENTAGE ANGIOSPERMS IN THE UPPER TERTIARY AND PLEISTOCENE OF THE LACHLAN VALLEY

(+) Present
(S) Shrub or small tree
(++) Common, present in most samples
(H) Herbaceous or ground cover
(T) Trace or rare
(R) Rainforest

PLANT TAXON	FOSSIL NAME	ELEMENT	Lower Myrtaceae Phase	*Nothofagus*/ Gymnosperm Phases	Upper Myrtaceae Phase	Pleistocene
Acacia	*Polyadopollenites myriosporites* 1	S	+	+	+	+
Banksieae	*Banksieaeidites elongatus* 1	S	+	+		
Chenopodiaceae/Amaranthaceae	*Chenopodipollis chenopodiaceoides* 4	H	+	+		
Cichorieae (of Compositae)	*Fenestrites* sp	H				+
Coelybogyne	*Psilatricolporites operculatus* 5	R	T			
Compositae	*Tubulifloridites* spp 2	H	+	+	+	++
Compositae	*Tubulifloridites pleistocenicus 2*	H				++
Cupanieae	*Cupanieidites* spp 1, 6	R		+		
Cyperaceae	*Cyperaceaepollis* spp 4	H	+	+	+	+
Dodonaea	*Dodonaea sphaerica* 2	S	+	+	+	+
Elaeocarpus	*Elaeocarpus comp* 3	R		T		
Epacridaceae	*Ericipites* sp 1	S	+	+	+	+
cf Goodeniaceae	—	S	+	T		
cf *Grevillea*	—	S		+		T
Gyrostemonaceae	—		T			
cf *Hakea*	—	S	+	+		
Haloragis	*Haloragacidites haloragoides* 1	H	++	++	++	++
Helicia-Orites	*Proteacidites ivanhoensis* 2	R	+	+	+	
Ilex	*Ilexpollenites* sp 1	R	T			
cf *Isopogon*	—	S	T	T		
cf Liliaceae	*Liliacidites* sp	H	+	T		T

APPENDIX 3 (Cont'd.)

PLANT TAXON	FOSSIL NAME	ELEMENT	Lower Myrtaceae Phase	*Nothofagus*/ Gymnosperm Phases	Upper Myrtaceae Phase	Pleistocene
Loranthaceae	Loranthaceae 3					+
Macaranga — Mallotus	*Triporopollenites endobalteus* 5	R	+			
Micrantheum	*Micrantheum spinyspora* 2	S	+		+	+
Monotoca	—	S	T	T	T	T
Myriophyllum	*Haloragacidites myriophylloides* 6	H	+	+	T	T
Onagraceae	Onagraceae 2	H				T
—	*Parsonsidites* 7		+			
—	*Polyporina granulata* 2					+
Proteaceae	*Proteacidites* spp	S	++	++	+	T
Quintinia	*Quintinia psilatispora* 2	R	+	+	+	
Restionaceae, *Hypolaena* type	*Milfordia hypolaenioides* 2	H	+	+	++	T
—	*Rhoipites alveolatus* 8 (= *Tricolporopollenites transversalis* 2)		+	+	+	+
cf. *Santalum*	—			T		
Sparganiaceae	*Sparganiaceaepollenites* sp 2	H	T		+	T
—	*Stephanocolpites oblatus* 2		++	++	+	T
cf. *Symphyonema*	*Proteacidites symphyonemoides* 2	S	+		T	
Symplocos	*Symplocoipollenites austellus* 1	R			+	
Tasmannia	*Drimys tetradites* 2	R	+	+	++	

References:
1. Stover & Partridge 1973
2. Martin 1973a
3. Luly *et al.* 1980
4. Truswell *et al.* 1985
5. Martin 1974
6. Cookson & Pike 1954b
7. Mildenhall & Crosbie 1979, Macphail & Mildenhall 1980
8. Pocknall & Crosbie 1982